

Evaluation of Non-Chemical Treatment Technologies for Cooling Towers at Select California Facilities



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Glossary of Terms

aq	aqueous
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
Ca	calcium
CaCO ₃	calcium carbonate
Ca(HCO ₃) ₂	calcium bicarbonate
CDPH	California Department of Public Health
CEC	California Energy Commission
CHC	Controlled Hydrodynamic Cavitation
CO ₂	carbon dioxide
CO ₃	carbonate
COC	cycle of concentration
DPR	Department of Pesticide Regulation
DTSC	Department of Toxic Substances Control
EBMUD	East Bay Municipal Utility District
EPA	Environmental Protection Agency
Evapco	Evapco West, Inc.
gpm	gallon per minute
H ₂ O	water
HCO ₃	bicarbonate
HPC	heterotrophic plate count
HVAC	heating, ventilation, and air conditioning
kVA	kilovolt-amp
LEED	Leadership in Energy and Environmental Design
MCL	maximum contaminant level
MIC	microbial influenced corrosion
µg/L	micrograms per liter
µS	microSiemens
µS/cm	microSiemens per centimeter
mg/L	milligrams per liter
mmhos	milliSiemens
OH ⁻	hydroxide ion
RWQCB	Regional Water Quality Control Board
SFPUC	San Francisco Public Utilities Commission
SWRCB	State Water Resources Control Board
TBC	total bacterial counts
TDS	total dissolved solids
TSS	total suspended solids
U.S.	United States
VOC	volatile organic compound

1 Introduction

Most water treatment chemicals have toxic or other hazardous properties that represent a risk to human health and the environment. Historically, phosphates, chromates, acids, chlorine and other biocides have typically been used to treat cooling tower water. Due to their high toxicity and persistence in the environment, some of these chemicals, such as chromates, are now prohibited from use in cooling towers.

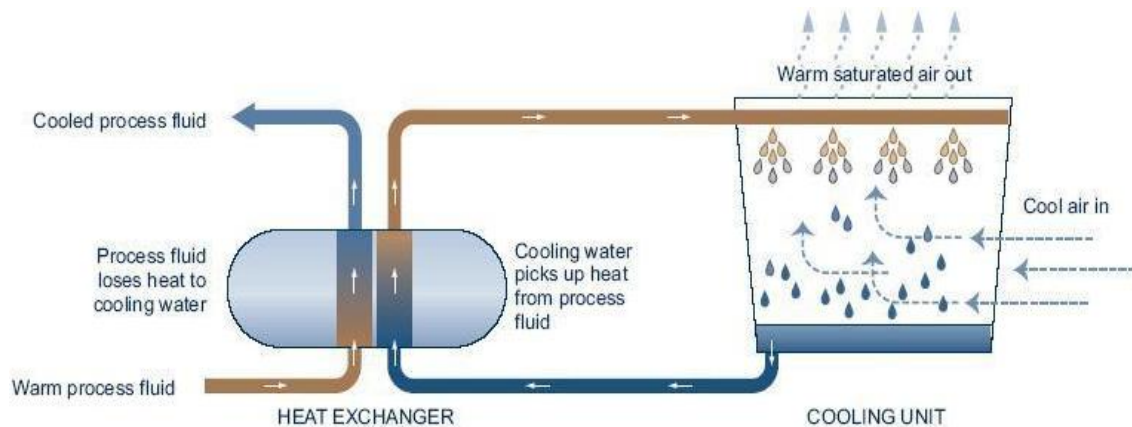
Several alternative technologies have recently become commercially available to treat water used in cooling towers without the use of chemicals. These non-chemical treatment technologies claim to have the capability to maintain a water chemistry that prevents scale and corrosion problems and inhibits adverse bacterial growth in cooling tower systems. This report evaluates two commercially available non-chemical cooling water treatment technologies that have been implemented in California.

Use of non-chemical treatment technology potentially offers additional advantages. Cooling towers utilizing non-chemical treatment technologies reportedly are able to operate at higher cycles of concentrations; this conserves water, as less blowdown wastewater is generated. Further nonchemical treatment technologies require only minimal maintenance as compared to chemical treatment approaches. Maintaining cooling tower water chemistry to control scale is critical for maintaining an energy efficient cooling tower. With chemical treatment constant monitoring and routine chemical additions are required to maintain water chemistry. Deviations from an established chemical maintenance program can result in adverse scaling and corrosion problems in the cooling tower system, making it less energy efficient. Costs for shutdown and aggressive maintenance to remove the scale or replace failed parts can be substantial. In the worst case, scale and corrosion problems can lead to tower failure and the expense of installing a new tower.

2 Overview of Cooling Tower Operation

Cooling towers can generally be classified by use into either HVAC (air-conditioning) or industrial duty. Industrial cooling towers can be used to remove heat from various sources such as machinery or heated process material. The primary use of large, industrial cooling towers is to remove the heat absorbed in the circulating cooling water systems used in power plants, petroleum refineries, petrochemical plants, natural gas processing plants, food processing plants, semi-conductor plants, and other industrial facilities.

A cooling system consists of a cooling unit (e.g., cooling tower) and a heat exchanger (see **Figure 1** below). Cool water is pumped from the cooling tower and circulated through a heat exchanger to remove heat (i.e., to cool) from hot process fluids generated in HVAC or other industrial process equipment. In the heat



exchanger cooling tower water is warmed as heat is transferred from the hot process fluid to the cooling water. The warmed water then returns back to the cooling tower. In the cooling tower, warmed water is sprayed downward, and air is blown upward with a fan. As the warm water droplets contact the air, some of the water droplets evaporate, and the air absorbs the heat released from this evaporation—thereby lowering the temperature of the remaining water. An outside source of water, commonly referred to as “makeup water,” adds more water to the system to make up for evaporation and other water losses. Then the water is recirculated back to the heat exchanging equipment and the process is repeated¹.

As this process is repeated, minerals in the recirculated water such as calcium carbonate (CaCO_3), iron and silica become concentrated. Calcium carbonate exists in the form of calcium (Ca^+) and bicarbonate (HCO_3) ions in water. As the temperature of water increases, the calcium ion precipitates because its solubility decreases with increasing water temperature. When the calcium ion precipitates, it forms an adherent deposit (scale). This scale forms preferentially on hot surfaces as

¹ City of San Jose, San Jose/Santa Clara Water Pollution Control Plant, *Guidelines for Managing Water in Cooling Systems for Owners, Operators, and Environmental Managers*, July 2002

the diffusion of calcium ions is accelerated by the relatively higher temperatures around the heat exchanger surface.² The heat exchanger transfers heat less efficiently as the scale builds up. This buildup also blocks water flow in the lines.

Historically, facility operators used chemicals to control conditions in the cooling towers caused by dissolved solids, dissolved gasses, organic compounds, suspended solids and microorganisms in the water. A properly managed chemical treatment program needed to be adjusted, monitored and controlled. In practice this was difficult to accomplish since a properly managed chemical program required constant adjustments due to changes in the system water and make-up water. Typically, scale formation was inhibited by using acids and threshold inhibitors, including polymers, polyphosphates, phosphonates or a combination of these chemicals, along with managed cycles of concentration. Anodic, cathodic, or combinational corrosion inhibitors were added to slow down corrosion by forming a protective layer on metal surfaces. Oxidizing and non-oxidizing biocides were added to control the growth of microorganisms.

Some treatment chemicals create additional problems or interfere with the performance of other treatment chemicals. Frequently acids are used to control scale and oxidizing biocides are used to control microorganisms. While low pH conditions enhance the effectiveness of biocides, both the acids and biocides attack metal causing corrosion. To neutralize the corrosiveness of water, and to a degree to offset chemicals added for scale and bacterial control, corrosion inhibitors are added. Some corrosion and scale inhibitors react with divalent cations in the system water to form a pseudo scale. However bacteria may utilize phosphate-based corrosion and scale inhibitors as a food source. Oxidizing biocides used to control bacterial growth break down certain types of scale/corrosion inhibitors; alkaline conditions necessary for the corrosion inhibitors to be effective can adversely impact oxidizing biocides and their half-life.

Additionally, a growing number of water treatment chemicals have come under even stricter laws in regards to their use and handling. Another consideration is the steadily increasing cost of chemicals, utilities, personnel training (e.g., training in proper handling, storage, and disposal of the chemicals), and maintenance. Finally, many industrial companies have corporate mandates to lower water usage and reduce chemical usage. These issues and the operational problems associated with traditional chemical treatment have caused many cooling tower and condenser users to consider use of non-chemical methods.

² Cho, Y.I, Lane, J, Kim, W., *Pulsed power treatment for physical water treatment*, International Communications in Heat and Mass Transfer, 32, 2005, pp. 861-871.

3 Description of Cooling Tower Treatment Technologies

For this demonstration, two types of emerging non-chemical treatment technologies in the California market place were considered.

- Controlled Hydrodynamic Cavitation (VRTX)
- Electrical Technologies-Pulse power (Clearwater Dolphin System™)

At the time of the demonstration, the Clearwater Dolphin System™ was the only pulsed power system known on the market. Since the demonstration began, Evapco has also introduced a device which they describe as a pulsed power non-chemical treatment system. For the purposes of this report, only the Dolphin System™ was evaluated and discussed.

3.1 Operation of the VRTX technology

As illustrated below, the VRTX technology system is a side-stream treatment application. It includes two parts: a mechanical unit and a separation/filtration

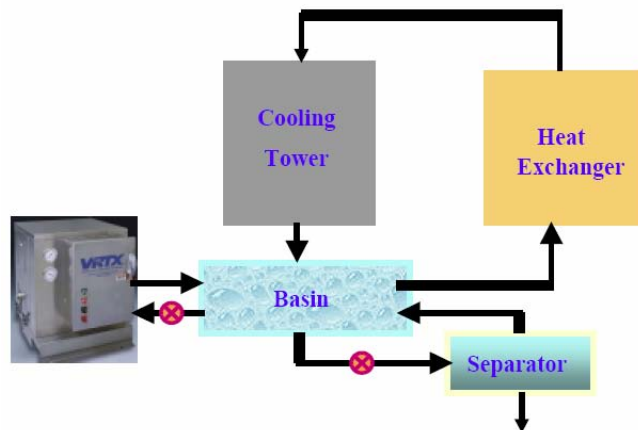


Figure 2. VRTX Process Flow Diagram

system. The separation/filtration system unit is used to remove the precipitated calcium carbonate and other suspended solids from the circulating cooling water.

The unit works primarily on the principle of Controlled Hydrodynamic Cavitation (CHC). Studies have found that in turbulent liquid flows, and notably at high velocity, hydrodynamic cavitation will occur. Cavitation is the dynamic process in a fluid where micro-sized bubbles form, grow, and collapse. When pressure falls below a critical value, cavities are formed in the liquid. When pressure increases, the cavities cannot sustain the surrounding pressure, and consequently, collapse creating localized points of extreme high pressure and temperature.

As the bubble collapses, the pressure and temperature of the vapor within it increases. The bubble will eventually collapse to a minute fraction of its original size, at which point the gas within dissipates into the surrounding liquid via a rather violent mechanism, which releases a significant amount of energy in the form of an acoustic shock-wave and as visible light. At the point of total collapse, the temperature of the vapor within the bubble may be several thousand kelvin, and the pressure several hundred atmospheres.

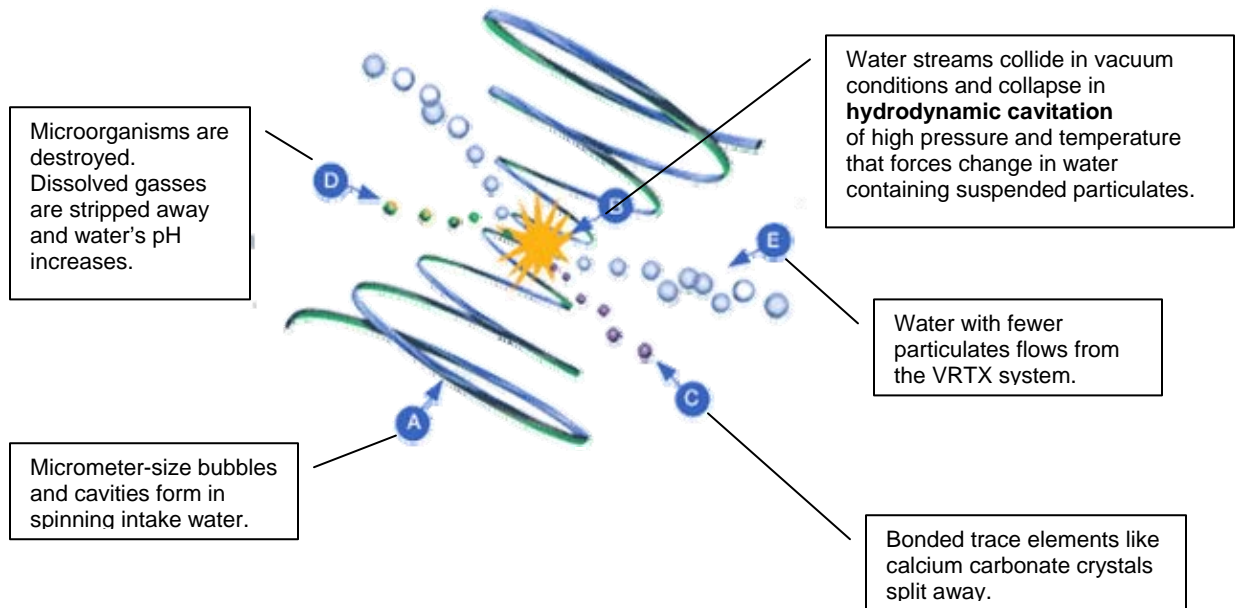


Figure 3. Conceptual Diagram of the VRTX Process

The patented process unit (see **Figure 4**), consists of a pressure equalizing chamber and a cavitation chamber. Water is pumped from the sump into the pressure-equalizing chamber at a constant pre-determined pressure. The water is then channeled through opposing nozzles that impart a specific rotation and velocity to the water streams. The flow and rotation of the water streams creates a high vacuum, usually 27.5 inches Hg to 29.0 inches Hg.

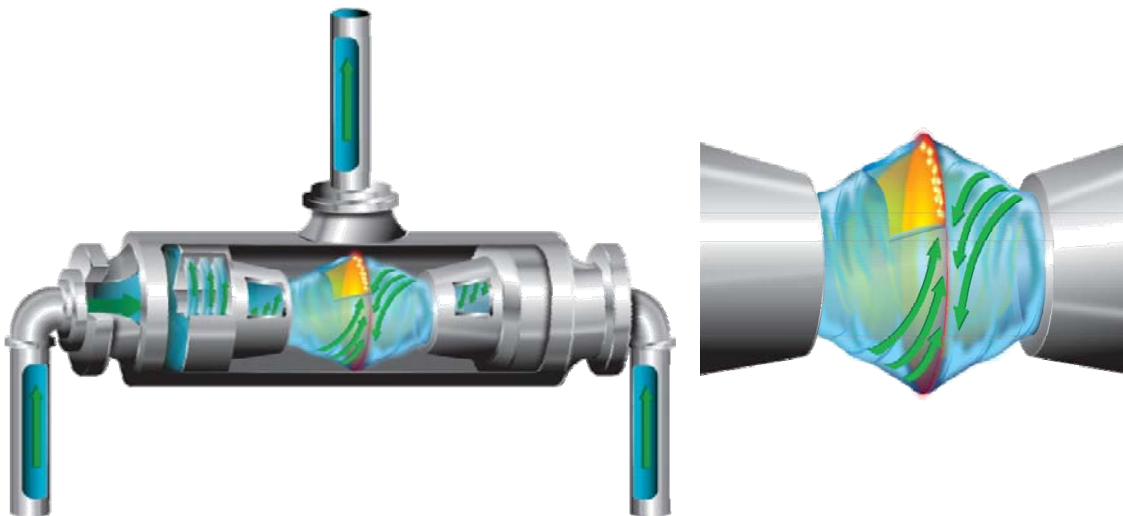


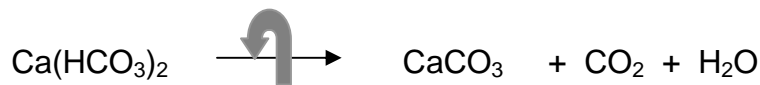
Figure 4. VRTX Process Chamber Diagram

The water streams in the opposing nozzles rotate in opposite directions and move forward with increasing velocity. Upon exiting from the nozzles, the water streams collide at the mid-point of the cavitation chamber. When the streams collide a region of high pressure is momentarily established causing vapor bubbles to collapse or implode. When a bubble collapses, an intensive shock wave and extremely high temperatures are generated that cause a shift in the water chemistry. The chemical reactions that then occur release CO₂ and other dissolved gases from solution.

The technology combines these effects to force the precipitation of calcium carbonate, control corrosion and kill microorganisms.

3.1.1 Scale Control

When the water undergoes cavitation in the chamber, the calcium bicarbonate (CaHCO₃)₂ in the water is forced to precipitate out in the form of calcite (CaCO₃). The following equation describes the reaction that occurs within the chamber.



In the chamber, the chemical equilibrium of the carbonate species in water is shifted, driving the above reaction to the right. As long as CO₂ is being removed the soluble calcium bicarbonate converts into insoluble calcium carbonate (from solution to suspension). The calcium carbonate crystals steadily grow and are easily removed from the water stream using a filtration system.

Hydrodynamic cavitation provides increased nucleation sites in the form of small-sized CaCO_3 colloids. These colloids then act as growth sites for other dissolved ions. Because continued crystal growth is thermodynamically favored over the formation of new nuclei (less required energy), the calcite crystals continue to grow in size. Coagulation increases due to greater mass attraction, and the filtration system then removes the larger particles that precipitate out.

Normally, when cooling water travels to various hot spots, dissolved calcium and bicarbonate tend to precipitate out as scale build-up because of the decrease in solubility. Mechanically treated water, however, behaves differently. Instead of forming nuclei on the equipment surface, dissolved ions will redirect their growth on the newly formed colloids.

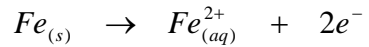
3.1.2 Bacteria Control

High vacuum, high pressure, high temperature, collision and mechanical shear are believed to contribute to the killing of various microorganisms. Microscopic examination revealed that the VRTX technology kills bacteria by physically rupturing the cell membrane. The exact mechanism is still under investigation. However, one or both of the following mechanisms are plausible:

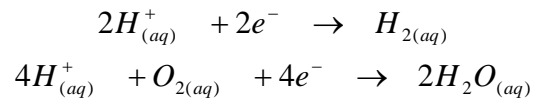
- Dramatic changes in pressure and vacuum – Water experiences dramatic changes in pressure/vacuum/pressure as it passes through the chamber. The membrane wall of bacteria is permeable and fragile. The cell membrane may be ruptured under such dramatic pressure changes in a period of seconds. The direct impact of shear and collision forces created by the colliding water streams would also contribute to cell wall destruction. Bacteria die once their cell membrane is broken.
- Hydrodynamic cavitation – When cavity bubbles collapse, an extremely high, localized temperature and pressure wave is momentarily created. The cell membrane of bacteria can easily be ruptured under these extreme conditions. Additionally, the cavitation process momentarily forms highly reactive oxidizing radicals and hydrogen peroxide, which are known disinfection or antimicrobial agents.

3.1.3 Corrosion Control

Corrosion, triggered by the pH decrease of the process water, is a common problem for cooling tower maintenance and equipment life. Because the circulating water in a cooling water system is highly aerated and contains oxygen, iron or other metals are oxidized when they come into contact with the circulating water. The following equation illustrates the anodic reaction:



These electrons released are then consumed by the hydrogen ion (H^{+}) in one of the following cathodic reactions:



The hydrogen ion concentration drives the above reactions. Because the concentration of hydrogen ions is exponentially proportional to pH, a small decrease in pH will substantially increase the hydrogen ion concentration.

Other important factors that affect the rate of corrosion are the chemical composition of the water, the concentration of dissolved gases, flow rates, temperature, microorganisms, and type of metal exposed to the circulating water. Dissolved gases such as oxygen, carbon dioxide, sulfur dioxide, and sulfur trioxide build up in cooling circulating water as a result of continuous aeration. These gases which are absorbed into the cooling system water from the air (much like a scrubber) also contribute to the oxidation of metal as shown in the above reactions.

The technology minimizes corrosion reactions by reducing the corrosiveness of the circulating water. Within the VRTX water stream a region of near perfect vacuum (27.5-29.5 inches Hg) forms, which degasses some of the CO_2 and other dissolved gases. This effectively elevates the pH of the bulk water to a non-corrosive level. Eliminating corrosive chemicals, maintaining relatively high pH levels, and controlling the growth of microorganisms combine to reduce corrosion reaction even at relatively high TDS levels.

3.2 Operation of the Clearwater Dolphin System™ Technology

The Clearwater Dolphin System™ delivers a combination of high frequency electric pulses and a varying DC electric field to the water as it passes through a solenoid coil. The system consists of two components:

- a) a transformer panel containing the electronics for pulse-generation, and
- b) a spool assembly piece consisting of an unobstructed flow pipe and multiple coils outside of the flow pipe

The Clearwater Dolphin System™ draws between 0.15 and 2.4 kVA, depending upon its size, and is available in pipe sizes from 1" diameter to 12" diameter. **Figure 5** illustrates the orientation of the coils.

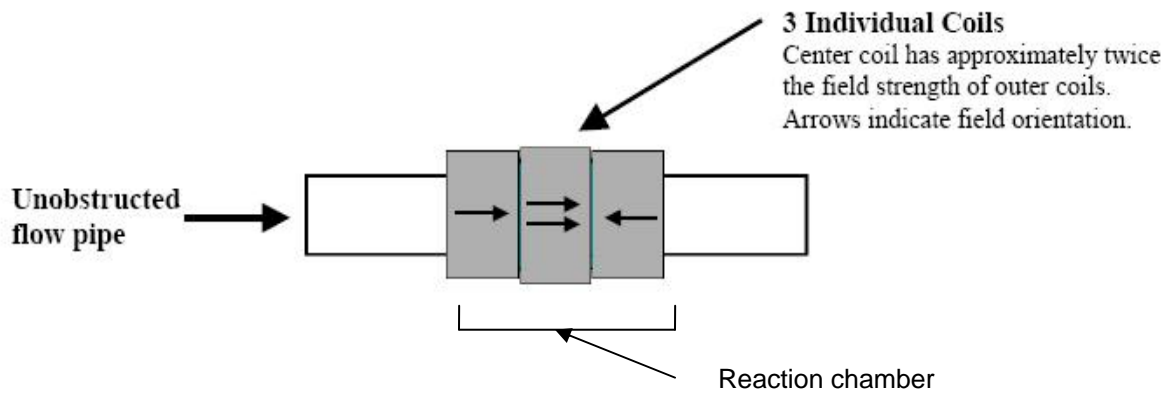


Figure 5. Clearwater Dolphin System™ Pulse Powered Device

The reaction chamber is essentially a section of PVC pipe wrapped with an intricate solenoid coil. Water flowing through this section of pipe is exposed to the pulsating electromagnetic field without coming into direct contact to the coil (see **Figure 5** above).

The Dolphin System™ imparts pulsed, high frequency electric fields into flowing water. The characteristic waveform is shown below.

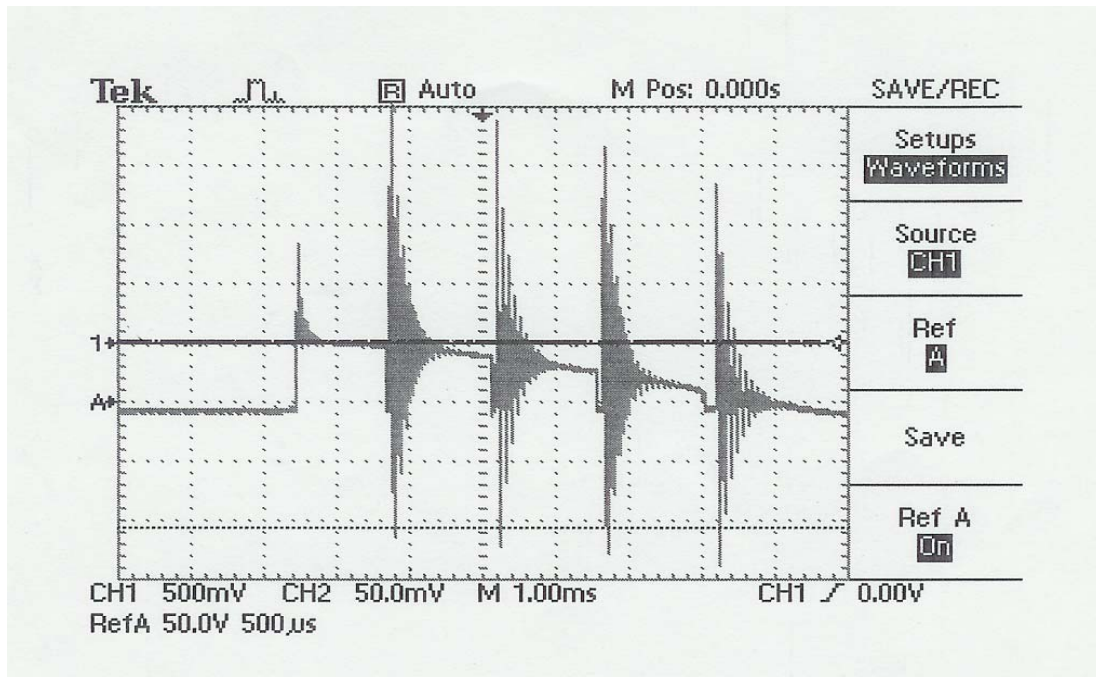


Figure 6. Characteristic Waveform Generated by the Clearwater Dolphin System™

The Clearwater Dolphin System™ is preferably located directly in front of the heat exchanger inlet. It may also be installed between the heat exchanger outlet and the cooling tower. According to the vendor, the Clearwater Dolphin System™ can also treat the process waters of chiller systems, heat exchangers, direct evaporative air-coolers (“swamp coolers”), steam boilers, some hot water systems and fountains.

3.2.1 Scale Control

When evaporation occurs in a cooling tower, the water exits the tower as water vapor and leaves dissolved minerals behind, causing increased concentration. When the concentration of a dissolved mineral exceeds saturation, dissolved minerals such as calcium carbonate (i.e., limestone) precipitate as a solid. The Clearwater Dolphin System™ changes the form of precipitated solids from a “hard lime scale” to a removable powder.

The Clearwater Dolphin System™ accomplishes this change by “activating” small-suspended particles that occur naturally in water. City water and well water contain large quantities of these suspended particles, which neither sink nor float because of their small size. The Clearwater Dolphin System™ treats the water by removing the static electric charge on the suspended particles thereby “activating” them. These activated suspended particles act as seeds for precipitation of dissolved minerals.

Dissolved minerals such as calcium carbonate (limestone) coat or adhere to the surface of the “activated” suspended particles. The particles grow in size until they precipitate out of the solution to form a powder-like solid, and thereby prevent scale from forming on the equipment surfaces. Without the Clearwater Dolphin System™ treatment, calcium carbonate and other dissolved minerals would precipitate and form scale on the equipment surfaces. This process is similar to seeding a cloud where particles are added to enhance water droplet formation to produce rain.

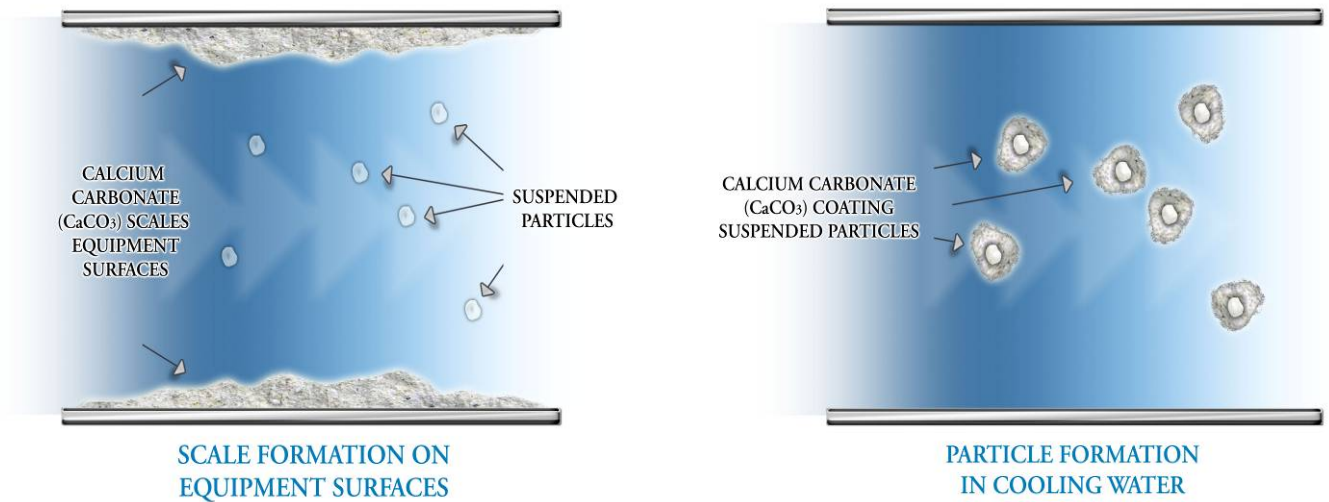


Figure 7. Difference in Scale Formation with and Without the Clearwater Dolphin System™

In removing the surface charge on suspended particles, the Dolphin System™ makes those particles the preferred sites for precipitation to occur. Thus, the minerals coat or adhere to the suspended particles rather than equipment surfaces. These coated particles form a powder that can be easily removed from a cooling tower basin by manual means, filtration, or centrifugal separation. The quantity of powder is typically about 15% of normal blown-in dirt in a cooling tower. Photomicrographs of the two mineral formations are shown in the following magnifications below:



Typical Surface Scale 60x



Bulk Solution Precipitate 60x
Dolphin Powder

Figure 8. Visual Difference of Scale Formed With and Without the Clearwater Dolphin System™

3.2.2 Bacteria Control

The Dolphin System™ has two mechanisms of controlling microbial populations in cooling systems: encapsulation and electroporation. As powder forms on the suspended particles, microbial life is encapsulated to the particle's surface, preventing it from reproducing. Since microbes have a 24 to 48 hour life span, any microbes not captured in the forming powder are “zapped” by a secondary pulse from the electric fields generated by the Dolphin System™. This secondary pulse damages the cell wall and forces the cell to repair itself rather than reproducing during its short life span. The combined effect of these two methods results in exceptionally low total bacterial counts (TBC) in cooling tower water. Sections 3.1.2.1 and Section 3.1.2.2 provide additional details on these methods.

3.2.2.1 Encapsulation

The limestone-type powder previously described that forms using the Dolphin System™ incorporates most of the free-floating (i.e., planktonic) bacteria. Without the Dolphin System™ treatment, the bacteria are repelled by the suspended particles due to the fact that nearly all tiny particles have similar negative static electric charges on their surfaces. Once the Dolphin System™ powder is growing, the repulsion to bacteria is eliminated; therefore, the bacteria are attracted to the powder by other natural forces (i.e., van der Waals forces) and become entrapped in the powder particle. The powder, in effect, removes the planktonic bacteria from the water and renders them incapable of reproducing.

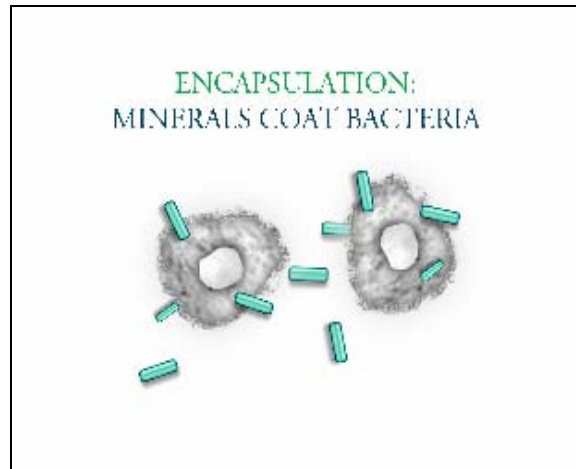


Figure 9. Encapsulation of Bacteria into Mineral Powder Formed Using the Clearwater Dolphin System™

3.2.2.2 Electroporation

The high frequency, pulsing action of the Dolphin System™ electric fields damages the membranes of planktonic bacteria by creating small “pores” in their outer membrane. The condition weakens the bacteria and inhibits their capability to reproduce.



Figure 10. Electroporation of Bacteria Using the Clearwater Dolphin System™

3.2.2.3 Biofilm or Slime

Normally bacteria form a biofilm or slime layer on equipment surfaces. A biofilm consists of a slimy bacterial secretion that forms a protective canopy to protect the bacteria beneath it from chemical biocides. It is very slimy to the touch, four times more insulating to heat transfer than mineral scale, and is the primary cause of microbial influenced corrosion. The bacteria that live in a biofilm adhering to an equipment surface are called sessile bacteria and represent 99% of the total bacteria in a system. The Dolphin System™ eliminates the slime layer through the process of nutrient limitation. By removing microorganisms and their potential decay products, the encapsulation and electroporation processes effectively reduce nutrient levels in the system. Thus the biofilm cannot be sustained and will not be created (or it will disintegrate it if one already exists prior to Dolphin System™ installation or operation).

3.2.3 Corrosion Control

For evaporative cooling equipment, the objectives of water treatment are to provide a good water chemistry environment minimizing uniform corrosion rates and preventing conditions which foster localized corrosion conditions. Of all the forms of corrosion, localized corrosion is of most concern because it can cause rapid deterioration and leaks in a system. Localized corrosion occurs when dissimilar water chemistry environments are created under scale or biofilm deposits adhering to system surfaces. Localized corrosion is difficult to predict or detect.

Uniform corrosion is characterized by the slow dissolving of entire metal surfaces and is of minimal concern. It rarely limits equipment life due to the corrosion resistance of the metals used in cooling tower construction. Corrosion coupons, which use the weight loss of a metal sample to measure uniform corrosion rates, are

a reliable method of corrosion monitoring. Galvanized sheet steel and stainless steel show very low uniform corrosion in Dolphin-treated systems. Copper and plain carbon steel experience minimal uniform corrosion within industry accepted norms in Dolphin-treated systems.

3.2.3.1 Localized Corrosion

The Dolphin System™ prevents one type of localized corrosion called microbial influenced corrosion (MIC). Biofilm formation is known to occur when high planktonic bacteria populations are present in a water-based cooling system. By maintaining low levels of planktonic bacteria, the Dolphin System™ prevents biofilm from forming and thereby eliminates the possibility for MIC to occur.

Mineral scale, formed on an equipment surface, causes another type of localized corrosion called under deposit corrosion. The Dolphin System™ prevents mineral scale from forming on the equipment surfaces thereby eliminating the conditions which leads to this type of corrosion.

Since the Dolphin System™ requires no chemical treatment additives, poor local corrosion environments due to chemicals inadvertently added or misapplied are avoided.

3.2.3.2 Uniform Corrosion

To ensure low uniform corrosion rates, the Dolphin System™ takes advantage of the natural corrosion-inhibiting powers of calcium carbonate. The Dolphin System™ manages cooling tower water chemistry so that calcium carbonate powder is always forming. Calcium carbonate in this saturation state acts as a powerful cathodic corrosion inhibitor. As such, it greatly slows the corrosion process by blocking the reception of electrons that are thrown off by the corrosion process. As the electrons have no place to go, the corrosion process is physically and very effectively controlled.

4 Field Sampling Objectives for Demonstration

A sampling program was conducted at select California facilities to evaluate the performance of the Clearwater and VRTX non-chemical cooling tower treatment systems in controlling scale formation and bacteria growth in water-based cooling towers. The regulatory issues associated with operating these units at select California facilities, and potential worker exposure associated with operating and maintaining these units were also addressed. Trend analyses were performed on data collected, as well as available historical data from past water sampling events at each facility. Sampling results were compared to applicable environmental discharge requirements and other regulatory requirements associated with operating these units.

Field Test Plan Objectives

Quantify Water Quality Performance Parameters. Analyzed water samples and evaluated if the unit met performance parameters specified for water-based cooling towers.

Regulatory/Permitting Requirements. Compared historical and grab sample data to the test facility's existing permit conditions and discharge requirements. Identify any potential regulatory or permitting issues that might be associated with use of this technology.

Worker Exposure. Measured noise level around these units prior to sampling.

Field Test Design

The analytes selected were based on parameters developed for maintaining chemically treated cooling towers. Alkalinity, hardness, fluoride, zinc, phosphate, calcium, silica and magnesium were analytes for monitoring scale potential. Copper, nickel and zinc concentrations are monitored for corrosion since they comprise of metals used in the tower structure. Nitrate, alkalinity, pH, TSS and chloride are also parameters monitored in chemically treated cooling towers for corrosion. Bacteria growth and potential were monitored based on bacteria plate counts and biological oxygen demand. VOC testing was included to determine if any volatile chemicals were present. In hindsight the VOC testing was probably not necessary due to the turbulent air flow that would cause these compounds to be released.

Test Runs

Dolphin and VRTX representatives identified three (3) separate facilities each for testing. A total of 486 samples were collected at the six facilities. Each facility was visited three separate times. Samples were collected from the sump and make-up inlet for the cooling tower on each visit. These water samples were analyzed for the

analytes listed in **Table 1**. **Table 2** lists the sampling schedule for each demonstration facility. When samples were collected, field readings for parameters such as pH, conductivity, temperature, turbidity, and alkalinity were also measured and recorded in a field notebook.

During the initial visit, information on the cooling tower make, model number, size, discharge location, automated monitoring systems, and bleed schedule were recorded. Photographs were also taken of the sampling locations and the cooling tower's orientation to existing buildings for most sites. Noise levels were monitored in the sampling area using the Quest SLM 2900 dosimeter.

Table 1. Summary of Field Sampling Activities

Method Number	Analytes	VRTX						Clearwater Dolphin Technologies					
		Trumer Brauerei ^a		Headway Technologies		Equinix, Inc.		Data Center		LBNL ^{a,b}		City of Berkeley	
		Sump	Make-up	Sump	Make-up	Sump	Make-up	Sump	Make-up	Sump	Make-up	Sump	Make-up
9215B	Bacteria Count	5 ^c	5 ^c	4 ^c	4 ^c	4 ^c	4 ^c	3	3	4	4	3	3
405.1	Biological Oxygen Demand (BOD)	4	4	3	3	3	3	3	3	4	4	3	3
310.1	Total alkalinity	4	4	3	3	3	3	3	3	4	4	3	3
300.0	Chloride, fluoride, nitrate, phosphate, sulfate	4	4	3	3	3	3	3	3	4	4	3	3
200.7	Calcium, potassium, silica (SiO ₂)	4	4	3	3	3	3	3	3	4	4	3	3
200.8	Copper, iron, magnesium, nickel, sodium, zinc	4	4	3	3	3	3	3	3	4	4	3	3
2340B	Hardness (as CaCO ₃)	4	4	3	3	3	3	3	3	4	4	3	3
	pH	4	4	3	3	3	3	3	3	4	4	3	3
160.2	Total suspended solids (TSS)	4	4	3	3	3	3	3	3	4	4	3	3
160.1	Total dissolved solids (TDS)	4	4	3	3	3	3	3	3	4	4	3	3
	Specific Conductance	4	4	3	3	3	3	3	3	4	4	3	3
8260	VOCs	4	4	3	3	3	3	3	3	4	4	3	3
Total number of samples		49	49	37	37	37	37	36	36	48	48	36	36
^a A replicate sample was collected at this facility.													
^b Lawrence Berkeley National Laboratories													
^c The first bacteria sample collected did not meet the holding time requirement outlined in the method. Another sample was collected a week later.													

Table 2. Project Sampling Schedule

Facility		Sampling Date		
		First	Second	Third
Berkeley		9/21/2006	10/17/2006	11/17/2006
LBNL		8/21/2006	9/21/2006	10/17/2006
Data Center		8/17/2006	9/13/2006	10/13/2006
Equinix		8/9/2006 8/16/06 ^a	9/5/2006	10/2/2006
Headway		8/9/2006 8/16/06 ^a	9/5/2006	10/2/2006
Trumer Brauerie		8/9/2006 8/16/06 ^a	9/5/2006	11/20/2006
Method Number	Analytes			
9215B	Bacteria Count	x x	x	x
405.1	Biological Oxygen Demand (BOD)	x	x	x
310.1	Total alkalinity	x	x	x
300	Chloride, fluoride, nitrate, phosphate, sulfate	x	x	x
200.7	Calcium, potassium, silica (SiO ₂)	x	x	x
200.8	Copper, iron, magnesium, nickel, sodium, zinc	x	x	x
2340B	Hardness (as CaCO ₃)	x	x	
	pH	x	x	x
160.2	Total suspended solids (TSS)		x	x
160.1	Total dissolved solids (TDS)		x	x
	Specific Conductance	x	x	x
8260	VOCs	x	x	x
^a On 8/16/06, samples were collected from the sump and make-up water inlet for TDS, TSS and bacteria. Samples for TSS and TDS were not collected on 8/9/06. Bacteria samples collected on 8/9/06 exceeded the method holding time which required resampling for bacteria. Blanks indicate no sample was collected on the day presented.				

5 Site Descriptions

5.1 Trumer Brauerei

The Trumer Brauerei is located in Berkeley, California and started operations in October 2004. The Berkeley facility is the second brewery opened by the parent company, Trumer Brauerei, located in Salzburg, Austria.

The brewery uses an open-top 400-ton cooling tower to cool its brewing facility. The cooling tower operates 24 hours a day, 7 days a week; it is only shut down intermittently during facility maintenance. The VRTX V-20 installed on this cooling tower treats 20 gallons of water per minute via a side-stream from the sump. A separate side-stream is filtered by a zero-gravity filter that consists of three 50-micron filter beds in series. These filter beds are backwashed with 10-15 gallons of water every 12 hours or when the differential pressure is equal to or greater than 10 pounds per square inch (psi).

Water from the sump is continuously monitored by a LMI Milton Ray conductivity meter. The meter has an upper limit set point of 1750 microSiemens (μS). When this set point is triggered, the bleed valve remains open and make-up water is added until the conductivity equals or is less than 1650 μS . The system valves are air actuated and require a constant air supply. **Table 3** summarizes these details. **Figure 11** shows a view of the cooling tower looking north and a close-up of the make-up water trough.

Table 3. Trumer Brauerei Cooling Tower Description and Operation

Cooling Tower and VRTX Unit Information	
Manufacturer	Baltimore Aircoil Company
Model Number	CXV-398 PR
Size	400 ton
Serial Number	96201083
Cooling Tower Installation Date	
Operating Schedule	24 hours when operating Intermittently off-line
Cooling tower water treatment system	VRTX V-20
Sidestream Filter Bleed Schedule	Cooling tower has a zero gravity filter on a timer to bleed the system every 12 hours or when the differential pressure is greater than 10 psi.
Automated Monitoring System	Yes
Manufacturer	LMI Milton Ray
Type	Conductivity meter
Set point	1750 μS . When set point is triggered, the bleed valve will stay open until the conductivity drops 100 μS (1650 μS).
Chemicals used for algae control?	No. A tarp covers the south-facing trough to control algae growth.

The primary water source for the cooling tower is city water supplied by East Bay Municipal Utility District (EBMUD). Approximately 90% of the water supplied by EBMUD is from the Mokelumne River watershed.³ Historical water quality data provided by the municipality is provided in **Table 9 in Section 6.1**



Figure 11. Cooling Tower at Trumer Brauerei

5.1.1 Sampling Locations

Water samples were collected from the cooling tower's make-up water inlet and sump. **Figure 12** shows the sampling location in the sump while **Figure 13** shows the sampling location for the make-up water.

³ East Bay Municipal Utility District, 2005 Water Quality Report.

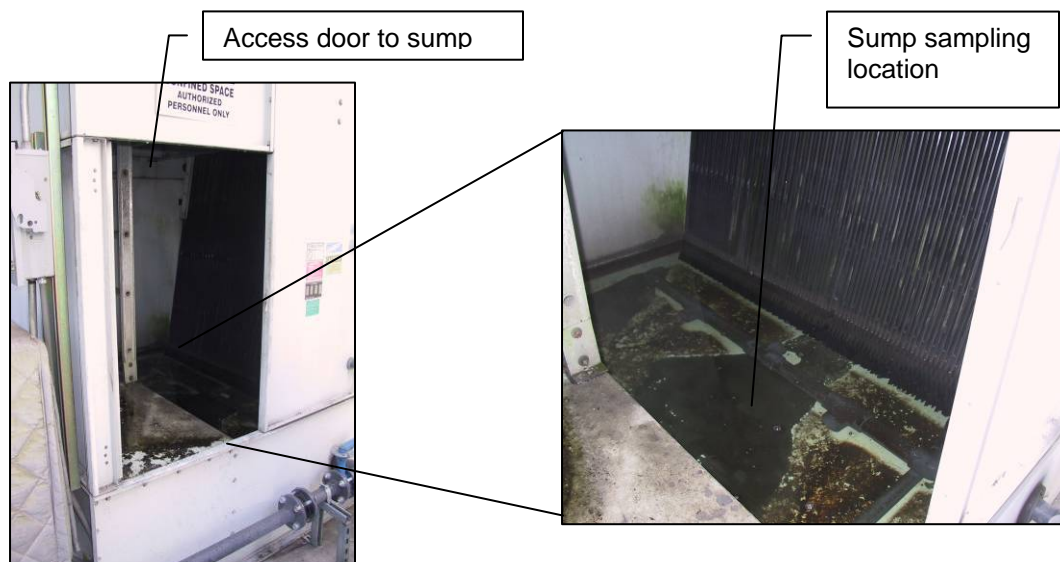


Figure 13. Sump Sampling Location (Trumer Brauerei)

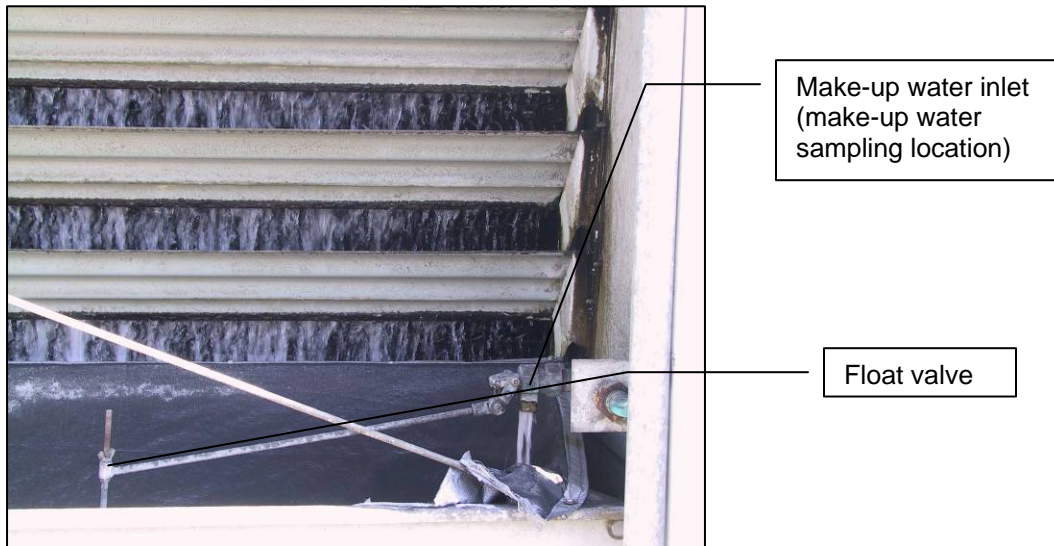


Figure 12. Make-up Water Sampling Location (Trumer Brauerei)

5.2 Headway Technologies

Headway Technologies, a subsidiary of TDK Corporation, designs and manufactures recording heads for high performance hard disk drives. Headway Technologies operates seven cooling towers at their San Jose facility; a 250-ton and 350-ton cooling towers on their south pad, two 400-ton cooling towers on the west pad, and a 500-ton and two 800-ton cooling towers on the North pad.

Headway Technologies installed the VRTX unit at one of the 800-ton cooling towers in 2005. The VRTX V-40 unit treats approximately 40 gpm of water that passes through a centrifugal filter prior to use in one of the 800-ton cooling towers. After treatment in the VRTX unit, a side-stream of treated water (7-8 gpm) is monitored via an in-line conductivity meter. The system blowdown is based on a timer set to open the bleed valve for 18 seconds every 8 hours. The system is also bled when the conductivity equals or exceeds 2500 $\mu\text{S}/\text{cm}$. The bleed valve remains open and make-up water is added until the conductivity equals or is less than 2400 $\mu\text{S}/\text{cm}$. The mechanical blowdown system was replaced with digital conductivity meters to reduce human error associated with monitoring the system flow. **Table 4** summarizes these details.

Table 4. Headway Technologies Cooling Tower Description and Operation

Cooling Tower and VRTX Unit Information	
Manufacturer	Baltimore Aircoil Company
Model Number	3654-MC
Size	800 ton
Serial Number	---
Cooling Tower Installation Date	2005
Operating Schedule	24 hrs/day, 7 days/wk, 52 wks/yr
Cooling tower water treatment system	VRTX V-40
Bleed Schedule	Primary schedule requires the system to be bled for 18 seconds every 8 hours unless the conductivity equals or exceeds 2500 $\mu\text{S}/\text{cm}$.
Automated Monitoring System	Yes
Manufacturer	LMI Milton Ray
Type	Conductivity
Set point	2500 $\mu\text{S}/\text{cm}$. A solenoid valve is opened and remains open until the conductivity reads 2400 $\mu\text{S}/\text{cm}$.
Chemicals used for algae control?	No



**Figure 14. Cooling Tower
(Headway Technologies)**

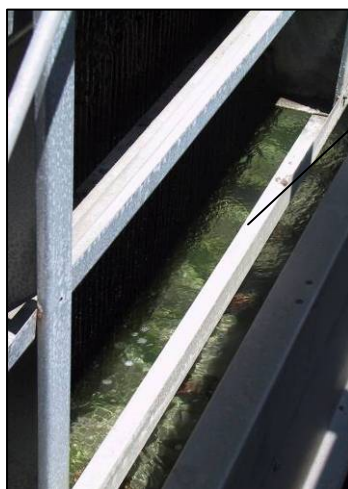


**Figure 15. Cooling Tower Baffles
(Headway Technologies)**

These cooling towers use municipal water provided by the City of Milpitas. The source of municipal water varies without warning and may consist of: (1) water from the Hetch Hetchy reservoir, (2) groundwater, (3) a blend of groundwater and water from the Hetch Hetchy reservoir, or (4) a blend of water from the California Aqueduct, groundwater, and the Hetch Hetchy reservoir.⁴ Historical water quality data provided by the municipality is provided in **Table 9 in Section 6.1**.

5.2.1 Sampling Locations

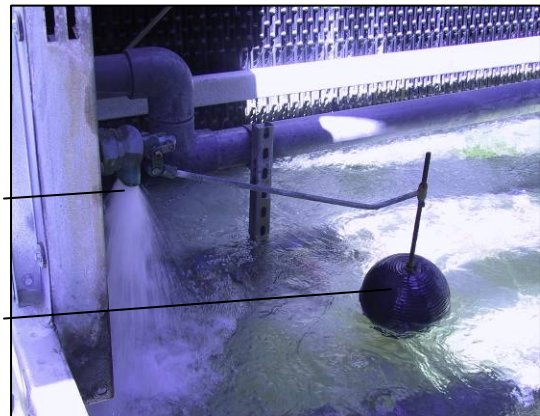
Water samples were collected from the cooling tower's make-up water inlet and sump. **Figure 16** shows the sampling location in the sump while **Figure 17** shows the sampling location for the make-up water.



Water for
Sump

Make-up
water inlet

Float valve



**Figure 16. Sump Sampling Location
(Headway Technologies)**

**Figure 17. Make-up Sampling Location
(Headway Technologies)**

5.3 Equinix

The Equinix facility, located in San Jose, California, is a data center and server farm. The facility was constructed in 2000 at the height of the Dotcom business boom. Five cooling towers are used as part of the facilities heating, ventilation, and air conditioning (HVAC) system. When the facility was constructed, three VRTX units were installed to inhibit corrosion and scale growth in these five cooling towers. Chemical treatment has never been used to maintain the scale and corrosion conditions in these towers. Equinix operates three cooling towers 24 hours a day, 7 days per week while the other two are operated at a reduced rate and available as a back-up system.

Each VRTX V-60 unit is capable of treating 60 gpm of water. The treated water is monitored by an in-line conductivity meter. A timer opens a bleed valve for 18 seconds every 3 hours to blow down the towers. The cooling towers are also blown down when the conductivity exceeds 1450 ppm. When this occurs, the bleed valve is opened and closes when the conductivity is less than or equals 1343 ppm. **Table 5** summarizes the details regarding the cooling tower and the VRTX unit.

Table 5. Equinix Cooling Tower Description and Operation

Cooling Tower and VRTX Unit Information	
Manufacturer	Marley
Model Number	NC Series NC 158997-001, NLB221BN-00
Size	500 ton
Serial Number	---
Cooling Tower Installation Date	2000
Operating Schedule	24 hrs/day, 7 days/week
Cooling tower water treatment system	VRTX V-60 (3 units)
Bleed Schedule	The primary schedule requires the tower be bled for 18 seconds every 3 hours unless the conductivity equals or exceeds 1450 ppm (2164 $\mu\text{S/cm}$).
Automated Monitoring System	Yes
Manufacturer	Walchem
Type	Conductivity meter, system bleed, and water feed
Set point	The conductivity meter's upper set point is set at 1450 ppm (2164 $\mu\text{S/cm}$). Once the upper set point is triggered, the system is bled until the conductivity equals or is less than 1343 ppm (2004 $\mu\text{S/cm}$).
Chemicals used for algae control?	No

⁴ City of Milpitas, 2006 *City of Milpitas Consumer Confidence Report*, June 2006.

In the Winter/Spring 2006, Equinix performed a video survey of their chiller lines condition. Equinix periodically checks the chiller lines to determine if they need to be clean. According to Equinix, no build-up was observed in the lines.

On the initial site visit for this project, Equinix indicated scale was removed from the baffles on one cooling tower. The scale was removed using a power washer and abrasive brushes.

The Equinix facility has three sources of water. The primary water supply is municipal water supplied by the City of Milpitas. The facility also has a large emergency reserve tank filled with city water and an on-site groundwater well for emergencies. The source for municipal water provided by the City of Milpitas may vary without warning. The source may consist of: (1) water from the Hetch Hetchy reservoir, (2) groundwater, (3) a blend of groundwater and water from the Hetch Hetchy reservoir, or (4) a blend of water from the California Aqueduct, groundwater, and the Hetch Hetchy reservoir. Historical water quality data provided by the municipality is provided in **Table 9 in Section 6.1**.

5.3.1 Sampling Locations

Due to confidentiality concerns, photos for the sampling locations were not obtained.

5.4 Data Center

A Northern California data center operates two 500-ton Evapco cooling towers. Due to security issues, the name and location of the facility are not disclosed as part of the participation agreement between DTSC and the facility owner. Both cooling towers have been in operation since 1995 and run 24 hrs/day, 7days/wk. The Dolphin unit was installed in August 2004 to treat the recirculated water for the cooling towers and chillers. Water used by the cooling tower passes through a Tower-Flo sand filter that was installed prior to the Dolphin unit. During the initial site visit, the facility reported the sand filter was last cleaned in April 2006.

Table 6. Data Center Cooling Tower Description and Operation

Cooling Tower and Clearwater Dolphin Unit Information	
Manufacturer	Evapco
Model Number	AT12912B
Size	500 ton
Serial Number	95821OW
Cooling Tower Installation Date	1995
Operating Schedule	Operates 24 hrs/day, 7 days/wk, 365 days/yr
Cooling tower water treatment system	Dolphin
Bleed Schedule	Upper set point limit at 700 $\mu\text{S}/\text{cm}$. When the conductivity equals or exceeds 700 μS , the system is bled until the conductivity is lowered to 650 $\mu\text{S}/\text{cm}$. The system has no primary blowdown schedule triggered by time.
Automated Monitoring System	Conductivity meter
Manufacturer	Pulsafeeder
Type	DCS900
Set point	The upper conductivity limit is set at 700 $\mu\text{S}/\text{cm}$. When this set point is triggered, the system is bled until the conductivity is equal to or less than 650 $\mu\text{S}/\text{cm}$.
Chemicals used for algae control?	No

A conductivity meter and water meter are used for determining the blowdown cycle. When the conductivity equals or exceeds 700 $\mu\text{S}/\text{cm}$, the system is bled and fresh water (make-up water) is added to the system until the conductivity is equal to or less than 650 $\mu\text{S}/\text{cm}$.

The facility still has the water treatment chemicals on-site. In a secondary containment unit near the chillers, a container of Microbiocide No. 8, Skasol MB-X and Skasol 4035, manufactured by Skasol Incorporated, were observed.



Figure 19. Cooling tower (Data Center)

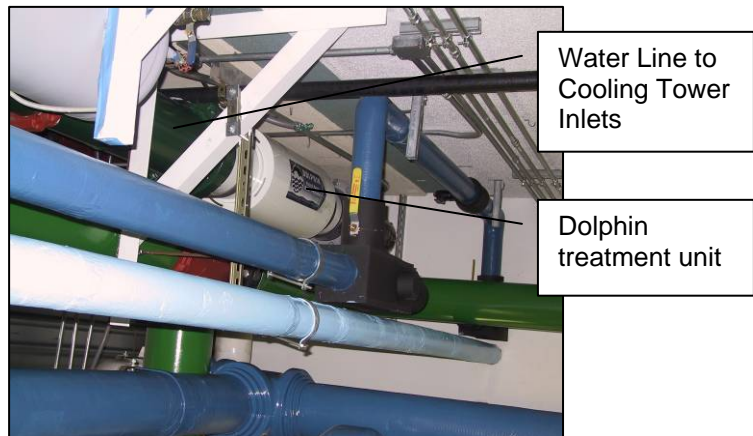


Figure 18. Dolphin and in-house plumbing lines (Data Center)

The cooling towers use water provided by the local municipality. Historical water quality data provided by the municipality is provided in **Table 14 in Section 7.1**.

5.4.1 Sampling Locations

Water samples were collected from the cooling tower's make-up water inlet and sump. **Figure 21** shows the sampling location in the sump while **Figure 20** shows the sampling location for the make-up water.



Make-up sampling location

Figure 20. Make-up water sampling Location (Data Center)



Sump sampling location

Figure 21. Sump Sampling Location (Data Center)

5.5 Lawrence Berkeley National Laboratories

Lawrence Berkeley National Laboratories (LBNL) is a science and engineering research facility located in Berkeley California. It is one of the oldest U.S. Department of Energy's National Laboratories. LBNL conducts unclassified research across a wide range of scientific disciplines with key efforts in fundamental studies of the universe; quantitative biology; nanoscience; new energy systems and environmental solutions; and the use of integrated computing as a tool for discovery. It is organized into 17 scientific divisions and hosts four DOE national user facilities.⁵

As part of this demonstration, one of two Clearwater Dolphin cooling towers at Building 62 was sampled. These cooling towers provide the primary cooling loop for the closed-loop heating, ventilation, and air cooling (HVAC) chillers, heat exchangers for the Low Conductivity Water (LCW) systems in Buildings 62 and 66, and provide the water supply to Building 72 for HVAC chillers and electron microscope cooling.⁶ The sampled cooling tower operates 24 hrs/day, 7 days/wk. When the cooling tower was installed in 1996, scale, corrosion and bacteria growth were treated using chemicals. In December 2004, LBNL installed a Dolphin 2080-PVC unit on the main tower water supply line header to the building equipment.

Table 7. LBNL Cooling Tower Description and Operation

Cooling Tower and Clearwater Dolphin Unit Information	
Manufacturer	Ceramre Cooling Tower
Model Number	XL-75-7P4
Size	330 ton
Serial Number	XL2179
Cooling Tower Installation Date	September 1996
Operating Schedule	24 hrs/day, 7 days/ wk
Cooling tower water treatment system	Model 2080-PVC Dolphin unit (8-inch dia.)
Bleed Schedule	The primary bleed schedule is determined by the conductivity meter. When the conductivity equals or exceeds the upper set point at 1,500 $\mu\text{S}/\text{cm}$, the bleed valve is opened. The bleed valve remains open until the conductivity is equal to or less than 1,450 $\mu\text{S}/\text{cm}$.
Automated Monitoring System	Yes
Manufacturer	LMI Liquitron™ DC4500
Type	Conductivity meter
Set point	Upper set point at 1,500 μS
Chemicals used for algae control?	No

⁵ Excerpt from the About Berkeley Laboratory on the Lawrence Berkeley National Laboratory web site at <http://www.lbl.gov/LBL-PID/LBL-Overview.html>.

⁶ Excerpt from the Pulse-power Non-chemical Water Treatment Study by Lawrence Berkeley National Laboratories, September 2005.

The 8-inch diameter Dolphin unit treats approximately 1,300-1,500 gpm and is monitored by an in-line conductivity meter. The system's bleed schedule is determined by the conductivity of the treated water. If the conductivity equals or exceeds 1,500 $\mu\text{S}/\text{cm}$, the bleed valve is automatically opened and remains open until the conductivity equals or is less than 1,450 $\mu\text{S}/\text{cm}$. No other chemicals are used to maintain the cooling tower. **Table 7** summarizes the details concerning the cooling tower and its operation.



Figure 22. LBNL Cooling Tower
(before Dolphin System was
installed)



**Figure 23. LBNL Dolphin
System™**

The primary water source for the cooling tower is city water supplied by East Bay Municipal Utility District. Approximately 90% of the water supplied by EBMUD is from a watershed of the Mokelumne River.³ Water quality data for 2005 is provided in **Table 14 in Section 7.1** for reference.

5.5.1 Sampling Locations

Sump and make-up water sample locations for the tower were similar to that of the other installations discussed in this report. Clear photos of the sump and make-up water sampling locations were not available.

5.6 City of Berkeley

The City of Berkeley facility is a six-story high rise office building located in Berkeley, California and houses several of the City's service organizations. This cooling tower is one of two cooling towers used to cool the building. The second cooling tower is not in use. In 2003, the City of Berkeley switched to the Dolphin System™. Prior to installing the Dolphin treatment system, the cooling tower was chemically treated.

Table 8. City of Berkeley Cooling Tower Description and Operation

Cooling Tower and Clearwater Dolphin Unit Information	
Manufacturer	Evapco West Inc.
Model Number	LSTA4181
Size	250 ton
Serial Number	872868
Cooling Tower Installation Date	Installed when building was open
Operating Schedule	24 hrs/7 days
Cooling tower water treatment system	Model 2060-PVC Dolphin (6-inch dia.)
Bleed Schedule	The primary bleed schedule is determined by the conductivity meter. When the conductivity equals or exceeds the upper set point at 1,500 $\mu\text{S}/\text{cm}$, the bleed valve is opened. Due to leaks in the cooling tower, the upper limit for conductivity is not achieved periodically.
Automated Monitoring System	Conductivity meter
Manufacturer	Pulsafeeder Series 300
Type	Conductivity meter
Set point	Upper set point set to 1,500 $\mu\text{S}/\text{cm}$
Chemicals used for algae control?	No



Figure 24. Cooling Tower and Dolphin System™ (City of Berkeley)

The primary water source for the cooling tower is city water supplied by East Bay Municipal Utility District. Approximately 90% of the water supplied by EBMUD is from a watershed of the Mokelumne River.³ Water quality data for 2005 is provided in **Table 14 in Section 7.1** for reference.

5.6.1 Sampling Locations

Water samples were collected from the cooling tower's make-up water inlet and sump. **Figure 25** shows the sampling location in the sump and the make-up water.

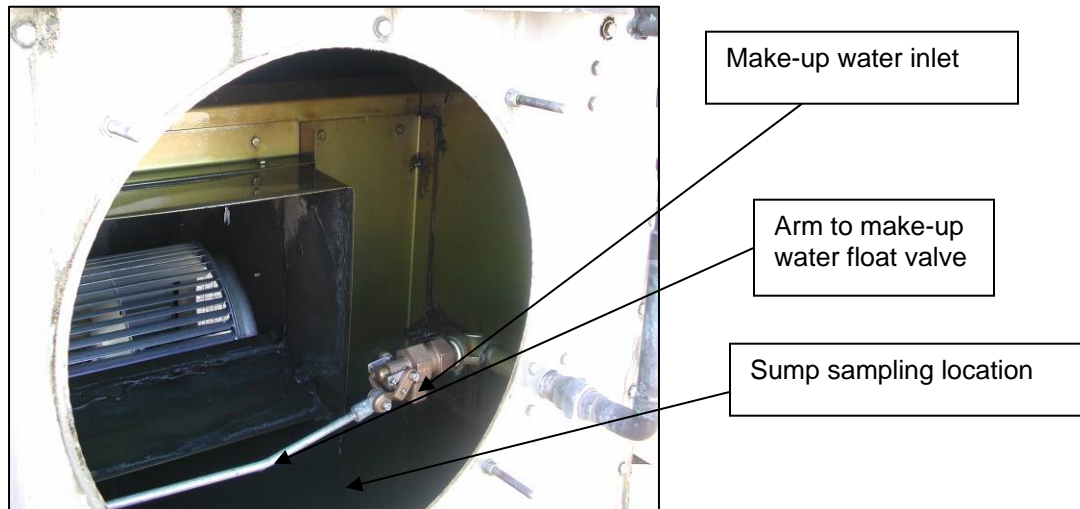


Figure 25. Sampling Locations (City of Berkeley)

6 VRTX Technology Results

Cooling tower make-up and sump water samples were collected and analyzed for different water quality parameters to assess the unit's performance at the three demonstration facilities using the VRTX non-chemical treatment technology.

6.1 Make-up Water Quality

The quality of the make-up water supply can greatly affect cooling tower operation and performance. A lower quality water supply can present a challenge to cooling tower operation, especially those using chemicals to treat the water. For chemically treated cooling towers, lower quality water generally means operating at lower cycles of concentration with greater blowdown wastewater generation. Cooling towers using alternative non-chemical treatment technology have the potential to operate at higher cycles of concentration given the same or similar make-up water quality.

Make-up water sample results for the three demonstration facilities were compared to historical water supply data as well as MCL drinking water standards for the different analytes. East Bay Municipal Utility District (EBMUD) supplies water to the Trumer Brauerei facility, while the City of Milpitas supplies water to both the Headway and Equinix facilities. These results are presented in **Table 9** below.

Table 9. Make-up Water Quality Data for VRTX Facilities

Water Quality Parameter	Concentration (mg/L) ^b					
	MCL	EBMUD ^c Water Supply	Trumer Brauerei Make-up Inlet	City of Milpitas ^e Water Supply	Headway Make-up Inlet	Equinix Make-up Inlet
Alkalinity, Bicarbonate (as CaCO ₃)	--	16.9-37.5	--	--	--	--
Alkalinity, Carbonate (as CaCO ₃)	--	1.6-2.2	--	6-150	56-67	57-77
Calcium	--	4.3-11	4.6-17	3-30	13-15	13-18
Chloride	500 ^a	4.3-6.3	4.2-10	<3-25	27-34	26-37
Fluoride	2	<0.1 ^d	ND-1.1	0.1-1.2 ^f	ND	ND
Hardness (as CaCO ₃)	--	14-58	12-63	8-150	32-38	33-45
Magnesium	--	0.8-2.7	0.78-5.1	<0.5-12.3	7.1-9	7.1-10
pH	--	8.6-9.3	8.6-8.89	7.87-11.04	7.8-7.96	7.82-7.96
Potassium	--	0.4-0.9	ND-1.3	<0.5-1.4	1.5-2.2	1.4-2.1
Silica	--	8.5-13.7	8.3-11	4.4-7.2	12	11-13
Sodium	--	5.3-12	5.5-21	3-26	26-31	27-30
Specific Conductance (µmhos/cm)	1600 ^a	61-140	56-220	24-435	260-360	260-380
Sulfate	500 ^a	1.3-16	ND-25	1-42	28-32	28-31
Total Dissolved Solids	1000 ^a	40-88	72-120	20-210	200-220	190-230

	Concentration (mg/L) ^b
-- = Not available ^a Secondary MCLs ^b All concentrations are in mg/L, except for Specific Conductance, reported in units of µmhos/cm. ^c The 2005 water quality data for the Orinda Treatment Plant is reported above since it services the Berkeley area and Trumer Brauerei. The EBMUD Orinda Treatment Plant receives its water from the Pardee Reservoir. ^d Reported is the amount detected in the source water before fluoridation. EBMUD adds fluoride between 0.9 to 1.0 mg/L to prevent dental decay in consumers. ^e The 2005 water quality data from the San Francisco Public Utilities Commission (SFPUC) is presented above. The SFPUC is the provider of Hetch Hetchy water supply to the City of Milpitas which serves the Headway and Equinix facilities. ^f The fluoride amount reported by the City of Milpitas is for fluoridated water.	

6.2 Cooling Water Sample Matrix

Water samples taken from the cooling tower sump are representative of the recirculating water quality being maintained in the tower. The results for sump water samples were compared to performance parameters developed by the cooling tower manufacturer, VRTX, and the San Jose/Santa Clara Water Pollution Control Plant. The applicable performance or operating parameters for the cooling tower systems demonstrated are given in **Table 10**, along with the MCL drinking water standard as a reference. The results for sump water samples collected as part of this demonstration and historical data are presented in **Table 11** below.

Table 10. Cooling Tower and VRTX Performance Parameters

Analyte	Units	Operating/Performance Parameters				MCL
		VRTX ^a	SC ^b	BB ^c	Marley ^d	
pH	pH units	8.0-9.4	--	6.5-9	6.5-8	6.5-8.5
Alkalinity	ppm	50-600	--	500(max)	<500	--
Conductivity	µS/cm	<5250 1350-2700 ^e	--	1800	--	--
Chloride	ppm	<750	≤300	250(max)	--	250
Fluoride	mg/L	--	≤10		--	2
Nitrate (as NO ₃)	mg/L	--	≤300		--	45
Sulfate (as SO ₄)	mg/L	<750	--	250(max)	<250	250
Hardness (as CaCO ₃)	ppm	30-500	--	30-500	>50	--
Total dissolved solids (TDS)	mg/L	<3500 500-1200 ^e	--	1500(max)	--	500
Silica (SiO ₂)	mg/L	--	≤150	--	--	--
Bacteria Count	CFU/ml	--	<10,000	--	--	--

Operating/Performance Parameters			
-- = Not available ^a VRTX Treatment Guidelines per 7/20/2007 correspondence. ^b Guidelines for Managing Water in Cooling Systems for Owners, Operators, and Environmental Managers, San Jose/Santa Clara Water Pollution Control Plant, July 2002. ^c Table 1: Circulated Water Quality Guidelines for Baltibond Corrosion ^d Marley AV Cooling Tower, User Manual 98-1514D ^e VRTX specified these minimum and maximum values as control limits specifically for the Headway facility.			

Table 11. Analytical Results for VRTX Systems

Analyte	Units	Trumer Brauerei Results		Headway Technologies Results		Equinix Results	
		Historical ^a	Demo ^b	Historical ^c	Demo ^b	Historical ^c	Demo ^b
pH	pH units	7.26-8.8	8.46-8.6	7.4-9.15	7.8-9.15	8.4-9.05	8.87-9.05
Alkalinity	ppm	89-190	130-190	193-1024	340-440	141-532	390-450
Conductivity	µS/cm	429-986	490-670	1080-15000	2200-2700	776-7455	2300-2700
Chloride	ppm	25-76	34-45	86-1315	320-380	89-755	340-390
Fluoride	mg/L	--	3.1-6.3	--	ND-2.2	--	ND-2.1
Nitrate (as NO ₃)	mg/L	--	7-24	--	44-61	--	41-55
Sulfate (as SO ₄)	mg/L	--	42-80	--	230-440	--	240-400
Hardness (as CaCO ₃)	ppm	100-288	100-230	180-2058	180-300	170-1292	200-270
Total dissolved solids	mg/L	286-657	350-420	720-10000	1200-1800	517-4970	1100-1700
Silica (SiO ₂)	mg/L	--	26-49	--	82-130	--	88-120
Bacteria Count	CFU/ml	--	738-1700	--	3200-74000 ^d	--	6800-30000 ^d
^a The range reported here consists of the minimum and maximum values reported from 2004 to 2006 which includes the results of this demonstration. ^b The range reported here consists of the minimum and maximum value obtained as part of this demonstration. ^c The range reported here consists of the minimum and maximum values reported from 2005 to 2006 which includes the results of this demonstration. ^d Bacteria results for samples collected on 8/16/2006 and 9/5/2006 exceeded the local water district's guidance criteria set at less than 10,000 CFU/ml.							

For Trumer Brauerei, all parameters were within the performance parameters outlined by VRTX, the Santa Jose/Santa Clara guidelines for chemical cooling tower operation, and the cooling tower manufacture where available. Headway and Equinix had sulfate concentrations that exceeded the cooling tower manufacturer's recommended specifications. Headway also had TDS concentrations that also exceeded the cooling tower manufacturer's recommended specifications. For both the Headway and Equinix facilities, all parameters were within the performance parameters outlined by VRTX. However, for both the Headway and Equinix facilities the chloride and two of the three bacteria results exceeded the Santa Jose/Santa Clara guidelines. The VRTX

representative was notified of the elevated bacteria count samples for the two samples collected at each facility in August and September 2006. By October 2006, the bacteria counts were below the 10,000 CFU/mL criterion.

A number of analytes exceeded the MCL at the three facilities. This might be expected, as the non-chemical treatment systems allow the cooling towers to operate at the higher cycles of concentrations, effectively increasing the concentrations of all inorganic constituents. Fluoride concentrations were slightly higher than the MCL at Trumer Brauerei. Chloride, nitrate, sulfate and TDS levels were higher than the MCLs in the demonstration samples and some historical samples at the Headway Facility. Similarly, pH, chloride, nitrate, sulfate, and TDS levels were higher than the MCL in the demonstration samples and some historical samples at the Equinix facility. The blowdown waters from these cooling towers discharge to the sanitary sewer which is typical for most installations. The sanitary districts do not have facility specific criteria concerning these contaminants and are not concerned with the slightly elevated reading of fluoride or the elevated levels of secondary drinking water contaminants discharged to the sanitary sewer system.

6.3 Cycles of Concentration

Cycles of concentration (COC) provide a measurement of how long the same water can be used or recirculated by the cooling tower before blowdown. The higher the COC that a system will support, the less make-up water is required and the greater the water conservation. Depending on the make-up water quality, two to four cycles of concentration are typical for a conventional cooling tower with chemical water treatment.

COC is typically calculated by dividing the concentration of a conservative (non-precipitating) constituent such as chloride or sulfide in the recirculating water by the concentration in the make-up water. In some cases the total dissolved solids (TDS) concentration is used for the calculation. **Table 12** provides the range of COCs calculated for the VRTX equipped cooling towers at three facilities during the demonstration period.

Table 12. Cycles of Concentration Observed at VRTX Facilities

Analyte COC Based On	Facility					
	Trumer Brauerei		Headway Technologies		Equinix	
	Historical ^a	Demo	Historical ^b	Demo	Historical ^b	Demo
Chloride	2.3 to 10.2	3.8 to 10.2	3.0 to 38.7	8.4 to 14.1	1.6 to 19.1	9.2 to 13.1
TDS	2.0 to 8.3	3.6 to 4.9	2.9 to 38.3	5.7 to 9.0	1.5 to 17.2	5.7 to 7.4
^a The range reported here consists of the minimum and maximum values reported from 2004 to 2006 which includes the results of this demonstration.						
^b The range reported here consists of the minimum and maximum values reported from 2005 to 2006 which includes the results of this demonstration.						

Analyte COC Based On	Facility Average COCs					
	Trumer Brauerei		Headway Technologies		Equinix	
	Historical	Demo	Historical	Demo	Historical	Demo
Chloride	5.5	6.6	9.5	11.2	7.1	11.0
TDS	4.9	4.4	8.5	7.5	6.1	6.3

COCs were also calculated based on several other analytes or parameters measured in addition to chloride and TDS. Graphs of these calculated COCs are provided in **Appendix D**.

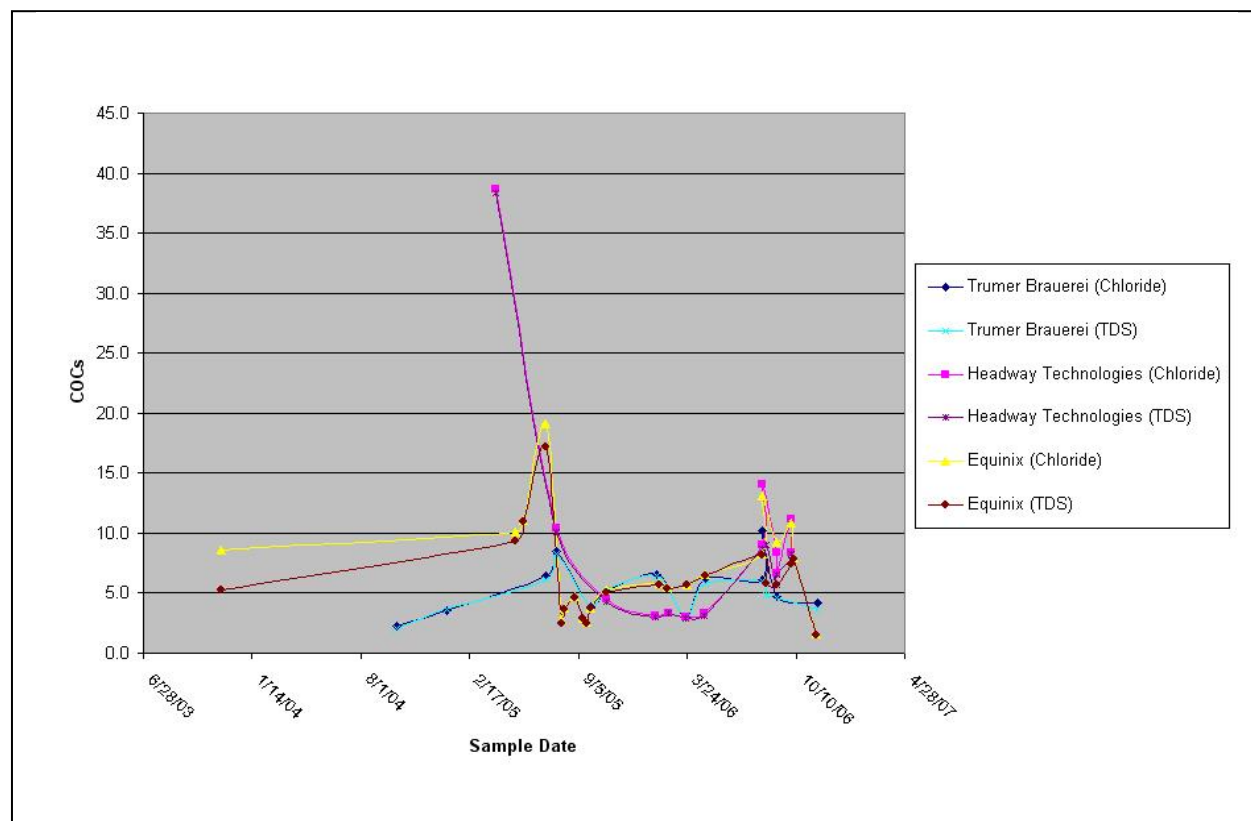


Figure 26. COC Chart for VRTX Demonstration Facilities Based on Chloride and TDS

6.3.1 Trumer Brauerei

The peaks may correspond to samples collected prior to a scheduled bleed for the zero gravity filters. Initially, the COCs were maintained in a range between 3 and 6 based on the chloride concentration. Presently, real-time TDS measurements are used to regulate the system blowdown which may account for the higher COCs. Most of the parameters fluctuate similarly over the data period with the pH remaining relatively constant. Drops in the COC may correspond to samples collected after the system

blowdown. The cycles of concentration (COCs) were also calculated for several different parameters and presented in **Appendix D**.

6.3.2 Headway Technologies

The initially high COC values in 2005 were associated with system start-up. After start-up, the COC were maintained between 3-5 COC from the 10/2005 to 3/2006. TDS concentrations measured using field instruments and an automated system was used during this period to regulate system blowdown along with conductivity. The sump water TDS was maintained between 500-1200 mg/L which was estimated to be 5-8 COC. During the 2006 demonstration period, the COC ranged from 4.6 to 14.1. The increase in the COC may be due to change in the blowdown operation. During the demonstration, TDS concentrations were greater than the maximum value used to determine blowdown in the past but less than the value provided by VRTX as a performance requirement. The cycles of concentration (COCs) were also calculated for several different parameters and presented in **Appendix D**.

6.3.3 Equinix

When the system was first started, real-time conductivity measurements were used along with laboratory results for chloride, TDS, alkalinity, pH, hardness, and conductivity to regulate system blowdown. VRTX established a monitoring range for TDS and conductivity concentrations of 900 to 1800 mg/L and 1350-2700 $\mu\text{S}/\text{cm}$ to keep the system operating between 5 and 8.5 COC. The COC was calculated based on the chloride concentration from laboratory results. In 2007, the TDS and conductivity upper ranges were increased to 3000 mg/L and 4500 $\mu\text{S}/\text{cm}$, respectively, due to an observed concentration increase for both analytes in the make-up water samples. This increase allowed the system to be operated closer to 7 COC.

During the 2006 demonstration period, the COC ranged from 9.2 to 13.1 when calculated based on the chloride concentrations. The cycles of concentration (COCs) were also calculated for several different parameters and presented in **Appendix D**. Based on the graph in **Appendix D**, it was also noted that the COC based on magnesium ranged between 7.6 and 12.3 while the remaining parameters had COCs ranging between 5 and 8.5. The fluctuating COC may be due to the samples collection relative to blowdown operation.

6.4 VOC Results

Make-up and sump water samples were also tested for volatile organic compounds to confirm no volatile organics were added as part of the cooling tower operation. The only compounds detected were trihalomethanes which are a by-product of drinking water chlorination.

Table 13 summarizes the VOC results. The total trihalomethane concentration detected in the make-up water samples were consistent with values reported by EBMUD or City of Milpitas, and were below the MCL. East Bay Municipal Utility District (EBMUD) supplies water to the Trumer Brauerei facility, while City of Milpitas supplies the Headway Technologies and Equinix facilities. The San Francisco Public Utilities Commission (SFPUC) is the provider for the Hetch Hetchy water supply to the City of Milpitas.

Table 13. Summary of VOC Results for VRTX Facilities

Analyte	Concentration (µg/L)								
	MCL	Water Districts		Trumer Brauerei		Headway Tech.		Equinix	
		EBMUD	SFPUC	Sump	Make-up	Sump	Make-up	Sump	Make-up
Total Trihalomethanes ^a	80	27-51 ^b	50.7 ^c	6	22.82-55.5	ND-3.3	14.5-44.1	ND	14.4-33.9
Bromodichloromethane	--	--	--	ND	1.2-5.2	ND-1.2	4.6-13	ND	4.3-10
Bromoform	--	--	--	--	--	ND	1.8-3.6	ND	2.3-3.9
Dibromochloromethane	--	--	--	ND	0.62-1.3	ND-1	5.6-8.5	ND	5.4-8
Chloroform	--	--	--	6 ^d	21-49	ND-1.1	2.5-19	ND	2.4-12
^a Total trihalomethanes includes bromodichloromethane, bromoform, chloroform, and dibromochloromethane (see Table 64533-A in California Code of Regulations (CCR) Section 64533). ^b Range reported for trihalomethanes detected in water treated at the Orinda Treatment Plant in 2005. ^c Highest running average reported for trihalomethanes detected in water treated by the San Francisco Public Utilities Commission (SFPUC) in 2005. ^d Detected in one sample on 9/5/2006.									

6.5 Potential Energy and Water Savings

Potential water and energy costs for each site are based on the engineering estimates provided in **Appendix E**. At each site, energy and water costs were estimated for the cooling tower based on two treatment scenarios. One scenario assumed the cooling tower was chemically treated while the other assumed the tower was treated using the VRTX system. These estimated costs are presented in **Table 14**.

For the chemically treated cooling tower, the tower was assumed to operate at 4 COCs. The chemical cost was based on a range from \$8-\$20 per ton of cooling annually which was listed in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) GreenGuide under Green Tip #14. The energy costs associated with the cooling tower fans and pumps were not calculated for either scenario since these costs were assumed to be similar.

The potential cost savings associated with operating the VRTX system result from less water discharged to the sanitary sewer and less scale and biofilm formed on heat exchange surfaces. Heat exchange efficiency is estimated to be reduced by 5% due to scale and biofilm build up which in turn reduces the energy efficiency of the cooling tower.

Table 14. Comparison of Potential Costs for VRTX and Chemical Treatment

Estimated Costs (\$/yr)	Trumer Brauerei		Headway Technologies		Equinix	
	Chemical	VRTX ^a	Chemical	VRTX ^a	Chemical	VRTX ^a
Make-up Water Fee	\$70,766.78	\$62,510.66	\$188,711.42	\$155,686.92	\$202,746.84	\$121,659.90
Bleed Water Discharge Fee	\$14,743.08	\$7,862.98	\$39,314.88	\$11,794.46	\$76,811.45	\$9,239.00
Chemical Cost	\$5,600.00	\$ 0.00	\$22,400.00	\$ 0.00	\$37,500.00	\$ 0.00
Maintenance & Labor Cost	\$ 400.00	\$ 0.00	\$1,600.00	\$ 0.00	\$2,500.00	\$ 0.00
Energy Cost due to Fouling	\$17,975.52	\$ 0.00	\$47,934.72	\$ 0.00	\$37,449.00	\$ 0.00
VRTX Operation Costs	\$ 0.00	\$11,983.68	\$ 0.00	\$17,975.52	\$ 0.00	\$80,889.84
Total Costs	\$109,485.38	\$82,357.32	\$299,961.02	\$185,456.90	\$357,007.29	\$211,788.74

^aThe costs associated with water use are based on the chloride derived cycles of concentration..

7 Clearwater Dolphin Technology Results

Cooling tower make-up and sump water samples were collected and analyzed for the different water quality parameters to assess the unit's performance at the three demonstration facilities using the Clearwater Dolphin System™ non-chemical treatment technology.

7.1 Make-up Water Quality

The quality of the make-up water supply can greatly affect cooling tower operation and performance. A lower quality water supply can present a challenge to cooling tower operation, especially those using chemicals to treat the water. For chemically treated cooling towers, lower quality water generally means operating at lower cycles of concentration with greater blowdown wastewater generation. Cooling towers using alternative non-chemical treatment technology have the potential to operate at higher cycles of concentration given the same or similar make-up water quality.

Make-up water sample results for the three demonstration facilities were compared to historical water supply data as well as MCL drinking water standards for the different analytes. These results are presented in **Table 15** below.

Table 15. Make-up Water Sampling Results for Clearwater Dolphin Facilities

Water Quality Parameter	Concentration (mg/L) ^b					
	MCL	City Data ^c Water Supply	Data Center Make-up Inlet	EBMUD ^d Water Supply	LBNL Make-up Inlet	City of Berkeley Make-up Inlet
Alkalinity, Bicarbonate (as CaCO ₃)	--	--	--	16.9-37.5	--	--
Alkalinity, Carbonate (as CaCO ₃)	--	--	16-41	1.6-2.2	30-65	20-77
Calcium	--			4.3-11	8.1-17	18-68
Chloride	500 ^a	2.90	3.4-3.6	4.3-6.3	5.6-9.9	4.4-11
Fluoride	2	0.80	ND-0.86	<0.1 ^e	ND-0.92	0.85-0.98
Hardness (as CaCO ₃)	--	27.50	22-24	14-58	20-62	45-150
Magnesium	--	--	--	0.8-2.7	1.2-4.6	4.3-15
pH	--	8.50	8.51-8.65	8.6-9.3	8.55-8.79	8.6-8.96
Potassium	--	--	--	0.4-0.9	0.71-1.2	1.2-5.7
Silica	--	--	--	8.5-13.7	8.5-9.7	8-68
Sodium	--	3.60	3.4-3.7	5.3-12	7.6-20	16-68
Specific Conductance (µmhos/cm)	1600 ^a	52.00	75-80	61-140	98-220	68-260
Sulfate	500 ^a	5.70	4.1-6.5	1.3-16	4.7-25	1.4-30
Total Dissolved Solids	1000 ^a	56.00	62-82	40-88	89-450	67-200

	Concentration (mg/L) ^b
-- = Not available ^a Secondary MCLs ^b All concentrations are in mg/L, except for Specific Conductance, reported in units of µmhos/cm. ^c The average value reported by the city utility district in their 2005 water quality data results are presented above. ^d The 2005 water quality data for the Orinda Treatment Plant is reported above since it services the LBNL and Berkeley facilities. The EBMUD Orinda Treatment Plant receives its water from the Pardee Reservoir. ^e Reported is the amount detected in the source water before fluoridation. EBMUD adds fluoride between 0.9 to 1.0 mg/L to prevent dental decay in consumers.	

7.2 Cooling Water Sample Matrix

Cooling tower sump water samples are representative of the quality of recirculating water being maintained in the tower. The results for these samples were compared to performance parameters developed by Clearwater Dolphin, the cooling tower manufacturer and the San Jose/Santa Clara Water Pollution Control Plant. The applicable performance or operating parameters for the cooling tower systems demonstrated are given in **Table 16**, along with the MCL drinking water standard as a reference. The results for sump water samples collected as part of this demonstration and historical data are presented in **Table 17** below.

Table 16. Cooling Tower Water Quality Performance Parameters for Clearwater Dolphin System™

Analyte	Units	Operating/Performance Parameters				MCL
		Dolphin ^a	SC ^b	Evapco ^c	Ceramre ^d	
pH	pH units	6.8-9.5 (8.5)	--	6.5-8.0	--	6.5-8.5
Alkalinity	ppm	--	--	50-300	--	--
Conductivity	µS/cm	500-8,000 (1,500)	--	--	--	--
Chloride	ppm	--	≤300	200	--	250
Fluoride	mg/L	--	≤10	--	--	2
Nitrate (as NO ₃)	mg/L	--	≤300	--	--	45
Sulfate (as SO ₄)	mg/L	--	--	--	--	250
Hardness (as CaCO ₃)	ppm	--	--	50-300	--	--
Total dissolved solids (TDS)	mg/L	100-4,000 ppm	--	--	--	500
Silica (SiO ₂)	mg/L	--	≤150	--	--	--
Bacteria Count	CFU/ml	<10,000 (2,000-4,000)	<10,000	--	--	--

Operating/Performance Parameters			
-- = Not available () indicate typical operating value per the evaluation criteria provided by Clearwater Systems. ^a Values from evaluation criteria for Dolphin by John Dresty of Clearwater Systems dated January 2003. ^b Guidelines for Managing Water in Cooling Systems for Owners, Operators, and Environmental Managers, San Jose/Santa Clara Water Pollution Control Plant, July 2002 ^c Evapco Bulletin 112X Maintenance Instructions ^d No recommended operating parameters could be found for this tower model.			

Table 17. Analytical Results for Clearwater Dolphin System™

Analyte	Units	Data Center Results	LBNL Results		City of Berkeley Results	
		Demo ^a	Historical ^b	Demo ^a	Historical ^c	Demo ^a
pH	pH units	8.6-8.65	7.95-8.76	7.95-8.76 ^d	6.5-8.96	8.64-8.87
Alkalinity	ppm	200-250	70-480	70-330 ^d	50-400	210-400
Conductivity	µS/cm	700-810	240-1490	240-1400 ^d	--	770-1400
Chloride	ppm	35-46	80-140	9.6-100 ^d	20-88	52-88
Fluoride	mg/L	7-11	--	1.4-13 ^d	--	7.4-8.1
Nitrate (as NO3)	mg/L	16-23	--	2.9-49 ^d	--	22-27
Sulfate (as SO4)	mg/L	51-83	--	24-270 ^d	--	56-410
Hardness (as CaCO3)	ppm	220-250	54-650	54-380 ^d	100-1000	13-430 ^e
Total dissolved solids	mg/L	500-560	--	150-1000	200-970	500-970
Silica (SiO2)	mg/L	85-92	--	17-110 ^d	--	8.3-69 ^e
Bacteria Count	CFU/ml	ND-40	48-1600	48-738	--	623-738
^a The range reported here consists of the minimum and maximum value obtained as part of this demonstration. ^b The range reported here consists of the minimum and maximum values reported from 2004 to 2006 which includes the results of this demonstration. ^c The range reported here consists of the minimum and maximum values reported from 2003 to 2006 which includes the results of this demonstration. ^d The make-up and sump samples collected on 9-21-06 had similar values for most values except bacteria count, BOD, copper, pH, TDS, and zinc. The sump sample may have been collected shortly after blowdown occurred. ^e Results for the sump and make-up inlet samples collected on 11-7-2006 for EPA Methods 200.7 and SM2340B appeared to have been switched when compared to the results collected before and after this sampling date.						

Results for the Data Center and City of Berkeley were compared to performance parameters developed by the cooling tower manufacturer (Evapco) and the San Jose/Santa Clara Water Pollution Control Plant. The manufacturer (Ceramre) does not specify performance parameters for the model of cooling tower used at LBNL. Results for LBNL were compared to the San Jose/Santa Clara Water Pollution Control Plant guidelines for cooling tower operation since there are no applicable local regulations. Demonstration results for the Data Center, LBNL and City of Berkeley were all within

the performance parameters outlined by the Santa Jose/Santa Clara guidelines or the cooling tower manufacturer.

Fluoride concentrations were slightly higher than the MCL for the three demonstration facilities, while pH was slightly higher than the MCL only for the Data Center facility. Since blowdown water from the cooling tower discharges to the sanitary sewer, these slightly elevated readings are not a concern.

7.3 Cycles of Concentration

Cycles of concentration (COC) provide a measurement of how long the same water can be used or recirculated by the cooling tower before blowdown. The higher the COC that a system will support, the less makeup water is required and the greater the water conservation. Depending on makeup water quality, two to four cycles of concentration are typical for a conventional cooling tower with chemical water treatment.

COC is typically calculated by dividing the concentration of a conservative (non-precipitating) constituent such as chloride or sulfide in the recirculating water by the concentration in the makeup water. In some cases, the total dissolved solids (TDS) concentration is used for the calculation. **Table 18** provides the range of COCs calculated for the Dolphin equipped cooling towers at three facilities during the demonstration period.

Table 18. Cycles of Concentration Observed at Clearwater Dolphin System™ Facilities

Analyte COC Based On	Facility					
	Data Center		LBNL		City of Berkeley	
	Historical	Demo	Historical ^b	Demo	Historical ^c	Demo
Chloride	N/A	10.0 to 13.5	1.5 ^a to 17.9	1.5 ^a to 17.9	2.0 to 11.8	8.0 to 11.8
TDS	N/A	6.9 to 8.5	N/A	1.7 ^a to 8.3	4.9 to 11.3	4.9 to 7.5
^a The make-up and sump samples collected on 9-21-06 had similar values for most analytes except bacteria count, BOD, copper, pH, and zinc. The sump sample may have been collected shortly after blowdown occurred.						
^b The range reported here consists of the minimum and maximum values reported from 2004 to 2006 which includes the results of this demonstration.						
^c The range reported here consists of the minimum and maximum values reported from 2003 to 2006 which includes the results of this demonstration.						

Analyte COC Based On	Facility Average COCs					
	Data Center		LBNL		City of Berkeley	
	Historical	Demo	Historical	Demo	Historical	Demo
Chloride	N/A	11.5	8.2 (8.5)	8.9 (12.7)	5.7	10.1
TDS	N/A	7.9	N/A	5.4 (7.2)	7.7	6.3

() is the adjusted COC average if the COC value reported for 9-21-06 was removed from the data set.

COCs were also calculated based on several other analytes or parameters measured in addition to chloride and TDS. Graphs of these calculated COCs are provided in **Appendix D**.

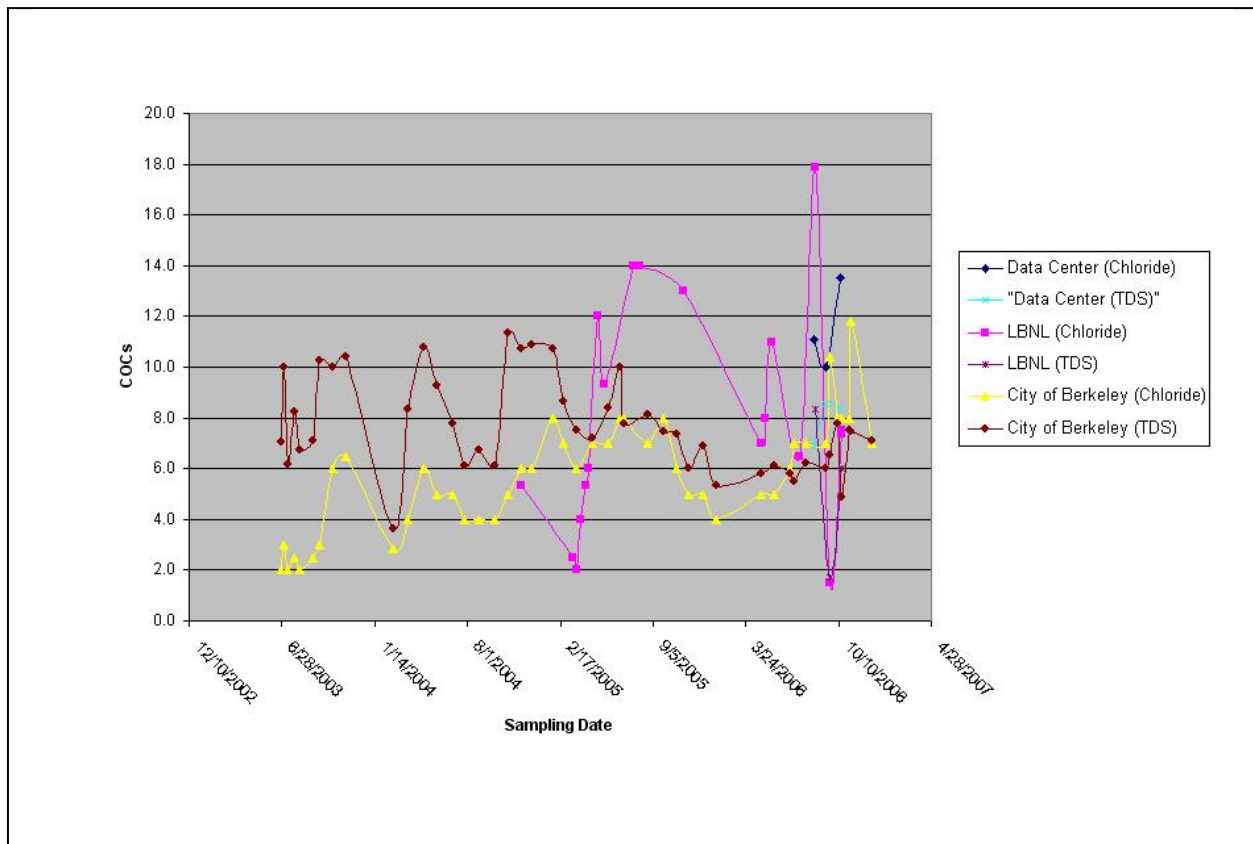


Figure 27. COC Chart for Clearwater Dolphin Demonstration Facilities Based on Chloride and TDS

7.3.1 Data Center

The COC ranged from 10 to 13.5 based on chloride concentrations for samples collected during the demonstration. Historical data for this site were not available to establish if these values were consistent with historical operating conditions. The COCs

calculated for several other parameters also ranged from 9 to 12 and are provided in **Appendix D**. For alkalinity and chloride, a drop in the COC value was observed in the second sample. The TDS COC remained unchanged between the second and third sample while the alkalinity and chloride COC increased along with a smaller increase of the conductivity COC. A smaller drop in the calcium COC was noted between the second and third sample as well. This may be an indication that the CaCO_3 was forming in the solution.

7.3.2 Lawrence Berkeley National Laboratories (LBNL)

Historically, this cooling tower was treated using chemicals and converted over to the Clearwater Dolphin System in April 2005. A 4-month period of data for the chemical treatment system was available and spanned between November 2004 and March 2005. COC graphs for alkalinity, chloride, conductivity, and hardness were plotted that include the period prior to using Dolphin system and are available in **Appendix D**.

When the Dolphin system was installed in April 2005, the in-line conductivity controller was set to 1500 $\mu\text{S}/\text{cm}$ to regulate the bleed cycle. Prior to using the Dolphin system, the COC concentration was around 3 based on the chloride concentration between November 2004 and March 2005. After the Dolphin system was installed, the average COC based on chloride concentrations was 8.2 and 8.9 based on historical and demonstration data, respectively. The average COC was 5.4 if calculated using the TDS concentration. However, the make-up and sump water samples collected on September 21, 2006 had similar values for most analytes except bacteria count, BOD, copper, pH, and zinc. One possible explanation is the sump sample may have been collected shortly after blowdown occurred. If the COC concentrations for chloride and TDS are calculated omitting this value, then the COC based on chloride concentration jumps to 12.7 and the COC based on TDS concentration to 7.2.

7.3.3 City of Berkeley

After the Dolphin system was installed, the average COC based on chloride concentrations was 5.7 based on historical data and 10.1 based on demonstration data. If the average COC was calculated using TDS concentrations, the value was 7.7 and 6.3 for historical and demonstration data, respectively.

Prior to January 2005, the conductivity set point was 800 $\mu\text{S}/\text{cm}$ and then increased to 1,000 $\mu\text{S}/\text{cm}$ to increase water savings. The lower COC values prior to January 2005 are probably due to the lower conductivity set-point. During the demonstration period, the set point was reported at 1,500 $\mu\text{S}/\text{cm}$ and would account for the higher COC observed.

7.4 VOC Results

Make-up and sump water samples were also tested for volatile organic compounds to confirm no volatile organics were added as part of the cooling tower operation. The only compounds detected were trihalomethanes which are a by-product of drinking water chlorination.

Table 19 summarizes the VOC results. The total trihalomethane concentration detected in the make-up water samples were consistent with values reported by EBMUD or the City Water Treatment Plant. East Bay Municipal Utility District (EBMUD) supplies water to the LBNL and City of Berkeley facilities, while the Data Center is serviced by an unnamed city's water district.

Table 19. Summary of VOC Results for Clearwater Dolphin System™ Facilities

Analyte	Concentration (µg/L)								
	MCL	Water Districts		Data Center		LBNL		City of Berkeley	
		EBMUD	City Data	Sump	Make-up	Sump	Make-up	Sump	Make-up
Total Trihalomethanes ^a	80	27-51 ^b	32-65 ^c	ND-4.2	45-63.1	ND	32.6-54.1	ND	34.3-45.3
Bromodichloromethane	--	--	--	ND	2-2.1	ND	1.8-5.4	--	--
Bromoform	--	--	--	ND	ND-2.1	ND	ND-0.91	ND	1.3-7.7
Dibromochloromethane	--	--	--	ND	ND-0.86	ND	0.81-1.2	ND	ND-1.6
Chloroform	--	--	--	ND-4.2	43-58	ND	30-47	ND	33-36
^a Total trihalomethanes includes bromodichloromethane, bromoform, chloroform, and dibromochloromethane (see Table 64533-A in California Code of Regulations (CCR) Section 64533). ^b Range reported for trihalomethanes detected in water treated at the EBMUD Orinda Treatment Plant in 2005. ^c Range reported for trihalomethanes detected in water treated at the City Water Treatment Plant in 2005.									

7.5 Potential Energy and Water Savings

Potential water and energy costs for the Data Center and the City of Berkeley facilities were based on the engineering estimates provided in **Appendix E**. The LBNL cost estimate is based on information from their September 2005 report entitled *Pulse-power Non-chemical Water Treatment Study Conducted at Lawrence Berkeley National Laboratory*. For the Data Center and City of Berkeley, energy and water costs were estimated for the cooling tower based on two treatment scenarios. One scenario assumed the cooling tower was chemically treated while the other assumed the tower was treated using the Dolphin system. These estimated costs are presented in **Table 20**.

For the chemically treated cooling tower, the tower was assumed to operate at 4 COCs. The chemical cost was based on a range from \$8-\$20 per ton of cooling annually which was listed in the ASHRAE GreenGuide under Green Tip #14. The energy costs associated with the cooling tower fans and pumps were not calculated for either

scenario. The initial purchase cost of the chemical and non-chemical treatment systems are not included in this analysis.

The potential cost savings associated with operating the Clearwater Dolphin system result from less water discharged to the sanitary sewer and less scale and biofilm formed on heat exchange surfaces. Heat exchange efficiency is estimated to be reduced by 5% due to scale and biofilm build up which in turn reduces the energy efficiency of the cooling tower.

Table 20. Comparison of Potential Costs for Clearwater Dolphin and Chemical Treatment

Estimated Costs (\$/yr)	Data Center		LBNL		City of Berkeley	
	Chemical	Dolphin ^a	Chemical	Dolphin ^a	Chemical	Dolphin ^a
Make-up Water Fee	\$117,944.64	\$96,714.60	\$ 203.00	\$ 26.00	\$44,229.24	\$36,562.84
Bleed Water Discharge Fee	\$24,571.80	\$6,880.10	\$ 354.00	\$ 46.00	\$9,337.28	\$2,948.62
Chemical Cost	\$14,000.00	\$ 0.00	\$9,400.00	\$ 0.00	\$3,500.00	\$ 0.00
Maintenance & Labor Cost	\$1,000.00	\$ 0.00	\$ 25.00	\$ 0.00	\$ 250.00	\$ 0.00
Energy Cost due to Fouling	\$29,959.20	\$ 0.00	N/A	N/A	\$11,234.70	\$ 0.00
Dolphin Operation Costs	\$ 0.00	\$ 473.04	\$ 0.00	\$ 125.00	\$ 0.00	\$ 473.04
Total Costs	\$187,475.64	\$104,067.74	\$9,982.00	\$ 197.00	\$68,551.22	\$39,984.50
^a The costs associated water use based on the chloride derived cycles of concentration are reported here.						

8 Regulatory Considerations

Part of the technology evaluation included a review of requirements for discharge of cooling tower wastewater or blowdown, chemical handling, storage, and disposal, and spill management. Other programs in the areas of pollution prevention and reuse were also reviewed.

8.1 Discharge Requirements for Cooling Towers

The applicable waste discharge requirements for cooling tower operation in California are too complex to be listed in this section. Water quality regulations are administered by the State Water Resources Control Board and the nine individual Regional Water Quality Control Boards. Each Regional board sets discharge requirements for their specific region. Local regulatory agencies set discharge requirements, which can also vary within each region for each analyte.

The demonstration facilities are located within the jurisdiction of the San Jose/Santa Clara Water Pollution Control Plant, East Bay Municipal Utilities District, and the City of Roseville. **Table 21** lists the waste discharge requirements for cooling water for these local agencies. These requirements do not consider whether the water was treated chemically or non-chemically.

Table 21. General Wastewater Discharge Requirements

Analyte	Discharge requirements* (mg/L)		
	SJ/SC ¹	EBMUD ²	No. Cal ³
Antimony	5.0	--	20.0
Arsenic	1.0	2	0.19
Beryllium	0.75	--	0.01
Cadmium	0.7	1	0.025
Chromium, total	1.0	2	0.56
Copper	2.7	5	0.25
Cyanides	0.5	5	0.13
Lead	0.4	2	0.6
Manganese	35.0	--	--
Mercury	0.010	0.05	0.002
Nickel	2.6	5	1.3
Phenol & derivatives	30.0	100	500.0
Selenium	2.0	--	0.006
Silver	0.7	1	0.04
TTO (Total Toxic Organics)	2.13	--	2.0
Xylene	1.5	--	--
Zinc	2.6	5	2.4
*Maximum allowable discharge quantities to sanitary sewers ¹ City of San Jose, San Jose/Santa Clara Water Pollution Control Plant, <i>Guidelines for Managing Water in Cooling Systems for Owners, Operators, and Environmental Managers</i> , July 2002 ² EBMUD Ordinance No. 311A-03, Section 3a ³ Roseville Municipal Code, Section 14.26.140, Specific pollutant limitations for industrial wastewater			

Although there are several tributyltin-containing products registered in California for use in recirculating cooling water systems, several California counties have prohibited their use such as San Francisco, Santa Clara, San Mateo, Alameda, Contra Costa, Solano, Napa, Marin, and Sonoma⁷ counties.

8.2 Chemical Handling/Disposal Requirements

Chemical handling and disposal practices for cooling towers treated using chemical treatment are significant when compared to those using non-chemical treatment alternatives.

For chemically treated cooling towers, several different types of chemicals are used to control corrosion, inhibit scale formation, control bacteria growth, and maintain pH. Anti-scaling agents work by interfering with crystal growth, and by inhibiting crystals from growing on tower surfaces. The primary anti-scaling agents used include sodium molybdate, phosphates and organic phosphonates, and polymers. The molybdate concentrations used in towers appear to be in the low ppm range, well below the STLC. Corrosion inhibitors may contain nitrite, molybdate, and orthophosphates. To control pH, chemicals such as commercial concentrated sulfuric acid (66° Baume), sulfamic acid, hydrochloric acid, nitric acid, and sodium bisulfate are used. Operators handling these chemicals need to be trained in hazardous materials handling and the use of appropriate personal protective equipment or PPE.

Industry generally categorizes biocides as oxidizing or non-oxidizing biocides. Oxidizing biocides include chlorine and bromine releasing chemicals and formulations, and other oxidants such as peroxides. Some of these biocides may be restricted pesticides and require the hiring a pesticides applicator certified by the California Department of Pesticide Regulation (DPR). According to the DPR, there are 200 pesticide products registered for use in cooling towers. **Appendix C** provides a list of these chemicals and their associated source categories. DPR tracked usage of cooling tower-related pesticides in 2003 and reported approximately 33,000 lbs used in California. Unfortunately, DPR appears to have limited their focus to agricultural-related applications after 2003.

Non-chemically treated cooling towers compared to the chemically treated cooling towers appear to use little to no chemicals. At one facility, the operator stated a mild bleach solution was used to control algae growth. At other facilities, it was reported only periodic cleaning of the tower baffles with stiff bristle brooms and a pressure washer was done. Other chemicals used to adjust pH, and control corrosion and bacteria growth were not observed during the site visits.

⁷ City of San Jose, San Jose/Santa Clara Water Pollution Control Plant, *Guidelines for Managing Water in Cooling Systems for Owners, Operators, and Environmental Managers*, July 2002

8.3 Spill Management

For chemically treated cooling towers, the chemicals used to control corrosion, scale and bacteria growth typically are stored in a secure area with secondary containment. Depending on the size of the container, it is secured to a wall or rack to prevent them from toppling. Chemical spill booms and absorbent material are needed in these areas in case material is accidentally released for quick containment and clean-up. Depending on the container size and local ordinances, a separate secondary containment system may be required to prevent releases to the sanitary or storm water sewer system.

Since no chemicals are used in the non-chemically treated cooling towers, the units do not require secondary containment or chemical spill booms or absorbent materials. However, depending on the location of the equipment and the local ordinances, spill booms or drain covers may be required to control accidental releases of cooling tower water.

8.4 LEED/Green Building Certified Technology

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ promotes adoption of sustainable green building and development practices. To accomplish this goal, the LEED program creates and implements universally understood and accepted tools and performance criteria. LEED is the nationally accepted benchmark for the design, construction and operation of high performance green buildings. LEED gives building owners and operators the tools they need to have an immediate and measurable impact on their buildings' performance. LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality.

The LEED program does not certify individual products but individual products can contribute points under the LEED rating system.⁸ Both of these non-chemical cooling tower water treatment technologies evaluated in this report have helped some projects garner points in water savings. **Table 22** lists three examples provided in the March 2008 LEED Innovative Design Credit Catalog. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) has listed pulse-powered chemical-free water treatment as a technology whose performance results have earned LEED points for certification in a number of projects⁹.

⁸ Frequently Asked Questions about the LEED Green Building Rating System, Fact Sheet, <http://www.usgbc.org/ShowFile.aspx?DocumentID=3330>

⁹ ASHRAE Green Tips 2006, ASHRAE Green Tip #14: Pulse-Powered Chemical-free Water Treatment

Table 22. Examples of LEED Projects

CIR/ID	CAT.	RS	Credit Title	A/D	Credit Description	
CIR	WE	NC	Non-Chemical Water Treatment: CIR	—	Ruling	An innovation point may be awarded for non-chemical water treatment.
					Intent	To reduce chemical and/or potentially hazardous discharges from the project site.
					Requirements	Use chemical-free water treatment technology in place of chemical treatment in site or building-related systems and clearly document that the strategy provides a significant environmental benefit
					Submittals	Description of the water treatment system used and a diagram of how the system works including: <ol style="list-style-type: none"> 1. The environmental benefit of the alternative system over a conventional system. 2. The chemicals and their quantities eliminated through the use of this alternative process. 3. The amount of treated water discharged or disposed of and in what quantities versus non-treated water. 4. The amount of waste water generated, the amount of treated versus non-treated water.
ID	WE	NC	Non-Chemical Water Treatment - Pulsed power	A	Intent	To reduce chemical and/or potentially hazardous discharges from the project site.
					Requirements	Install a water treatment system that requires no chemical treatments to maintain 100% efficient operation, and clearly document the environmental benefits of the system, including amount of waste water generated, the amount of treated versus non-treated water, the quantity and impact of each avoided chemical.
					Submittals	<ul style="list-style-type: none"> · Narrative outlining performance and environmental benefits · Manufacturer information · Comparative spreadsheet detailing water and chemical use for the base system compared to the design system using absolute values
CIR	WE	NC	Non-Chemical Water Treatment - Pulsed power	A	Ruling	Pulsed power process water treatment in HVAC equipment, while a controversial technology, may qualify for an innovation credit.
					Intent	Reduce the impact of potentially hazardous chemical discharges to the environment by eliminating conventional means of process water treatment in HVAC equipment. Reduce amount of water consumption from conventional recirculating water systems such as cooling towers, hydronic HVAC systems, or process water systems by decreasing the need for make-up water caused by evaporation and system blow down (or bleed).
					Requirements	Provide an integral chemical-free water treatment technology in place of conventional water treatment which uses potentially toxic chemicals which may also produce potentially hazardous chemical byproducts.

CIR/ID	CAT.	RS	Credit Title	A/D	Credit Description	
					Submittals	<ul style="list-style-type: none"> · A letter from the project engineer describing the chemical-free water treatment system used and how the system works · Narrative specifically stating the environmental benefits of using the chemical-free process in place of the conventional chemical water treatment system, specific chemicals and their estimated quantities eliminated by substituting the chemical-free process, and the methods and quantities of process water discharge as an estimate of potential water savings. · Proof that the technology works: a copy of a third-party analysis, letters from at least two of the vendor's previous clients that confirm the successful operation of this equipment.
Notes: For CIR/ID column, ID = Innovation in Design Credit and CIR =Credit Interpretation Request For Category (CAT.) column, WE = Water Efficiency For Rating System (RS) column, NC = New Construction For the A/D column, A/D indicates whether an ID credit was awarded (A) or denied (D) as originally submitted by the project team U.S. Green Building Council, Updated March 2008						

8.5 Re-use Potential

In many areas of California, recycled water is used for urban or agricultural irrigation. Urban settings include residences, parks, cemeteries, golf courses, and freeway landscaping. Agricultural settings include fields used to grow a large variety of crops including some edible crops. Irrigation methods vary and include furrow, spray, and drip irrigation methods. About two thirds of water that is recycled in California, or about 330,000 acre-feet per year, is used for irrigation.¹⁰ Since the blowdown water for cooling towers using either the Dolphin or VRTX systems is not chemically treated, the question of possibly reusing this water to irrigate landscape was raised.

The California State Water Resources Control Board (SWRCB) started developing a statewide Recycled Water Policy to establish more uniform requirements for recycled water projects. The proposed Policy includes the development of salt management plans, use of recycled water for irrigation, groundwater recharge reuse, compliance with SWRCB Resolution No. 68-16 (Statement of Policy with Respect to maintaining High Quality of Waters in California), and ongoing responsibility.

The Interim Salt Management Requirements for Irrigation Projects list five requirements for recycled water in basins where salt management plans are being developed. These interim requirements are to remain in effect while the salt management plans are being developed and are as follows:

¹⁰ State Water Resources Control Board, Draft Staff Report and Certified Regulatory Program Environmental Analysis Recycled Water Policy, February 2008.

- a) For all recycled water used within a basin, the monthly average concentration of total dissolved solids (TDS) in the recycled water shall not exceed the monthly average TDS of the source water supply, plus 550 mg/l.
- b) For recycled water used for irrigation, nutrient management practices shall be developed and implemented, if the concentration of nitrate in the recycled water exceeds 3 mg/l.
- c) For recycled water used for all irrigation, recycled water shall be applied in an amount that does not exceed the amount needed for the landscape or crops.
- d) For recycled water used for landscape irrigation, the Regional Water Quality Control Board (RWQCB) shall defer groundwater monitoring until the salt management plan has been approved, unless the RWQCB finds that site conditions such as shallow groundwater could cause an increased potential for an adverse effect on public health or surface water quality. Nevertheless, the RWQCB may require recycled water dischargers to monitor for salts, if necessary for salt management plan development and if similar informational burdens are imposed on other parties who may be contributing salt loadings to the underlying groundwater.
- e) During the time when the salt management plan is being developed, the RWQCB shall not require any other salt management measures than those stated in “a” through “d”.

Table 23 compares the TDS and nitrate values from the cooling tower effluent to the proposed interim requirements. Based on the values obtained for this demonstration, the blowdown (effluent) water from these cooling towers would exceed the interim requirements. Under the proposed Recycled Water Policy, the blowdown water treated by these physical treatment systems would not be suitable for landscape irrigation based on the nitrate and TDS.

Table 23. Comparing TDS and Nitrate Concentrations to Interim Requirements

Facility	Concentration (mg/L)				
	TDS			Nitrate	
	Effluent ¹	Source Water ²	Interim Req. ³	Effluent	Interim Req
Trumer Brauerei	350-420	40-88	614	7-24	3
Headway Technologies	1200-1800	20-210	665	44-61	3
Equinix	1100-1700	20-210	665	41-55	3
Data Center	500-560	56	606	16-23	3
LBNL	150-1000	40-88	614	2.9-49	3
City of Berkeley	500-970	40-88	614	22-27	3
¹ Listed values are for the effluent collected as part of this demonstration.					
² Values presented in this table are from the 2005 water quality reports issued by the local municipality.					
³ Determined based on the average TDS concentration + 550 mg/L.					

Since the requirements listed in **Table 23** are interim requirements, the reader is advised to consult their local county health department on the current requirements for using blowdown water to irrigate landscaping. The SWRCB and the Regional Water Quality Control Boards (RWQCB) also coordinate with the California Department of Public Health (CDPH) and the County Health Departments in managing the use of recycled water in California. These departments can also be contacted regarding the use of recycled water from cooling towers in landscape irrigation.

Conclusions

Based on the demonstration results, both the Dolphin and VRTX units have the ability to control scale, corrosion and pH effectively without the addition of chemicals. Although some scale build up was visible on the outside of some cooling towers, staff noticed the scale had a fluffy, granular texture and was easily removed from the surface by hand. Some algae were observed round the nozzles in the sump basin exposed to direct sunlight but no algae were observed on the outside of the towers.

The Dolphin unit consistently had bacteria counts between non-detect and 738 CFU/mL which was below the recommended operating guidance level of 10,000 CFU/mL for chemical cooling towers. The bacteria samples collected in October for the cooling towers equipped with the VRTX units were all below the 10,000 CFU/mL guidance level. However, samples collected in August and September at the two Santa Clara facilities were found to be above 10,000 CFU/mL. The reason for these elevated readings at two of the three demonstration facilities using the VRTX units is not known. It is recommended to monitor the bacteria content along with the other performance parameters closely at start-up.

Both the VRTX and Clearwater Dolphin systems increase the cycles of concentration within the cooling tower. The higher COCs means less makeup water is required and greater water conservation is achieved. Since both systems also effectively control scale formation, greater energy efficiency is also achieved.

Although these technologies provide an alternative to chemically treated cooling towers, facilities should still follow the best management practices established for chemical cooling towers:

1. Drain, clean, inspect and repair cooling towers at least once annually,
2. If the cooling tower is operated seasonally, follow the water treatment company's guidelines for water circulation during the off-season,
3. Use high quality conductivity controllers and clean the sensors on a bi-weekly basis,
4. Consider using software to continuously monitor the tower conditions,
5. Install water meters on the make-up and bleed lines and track your consumption, and
6. Consider installing a full port ball valve instead of a solenoid valve in the tower to the blow-down line to prevent clogging.¹¹

¹¹ SMUD, Pulse-Power Water Treatment Systems for Cooling Towers, November 10, 2003.

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United States Green Building Council, Frequently Asked Questions about the LEED Green Building Rating System, Fact Sheet,
<http://www.usgbc.org/ShowFile.aspx?DocumentID=3330>

VRTX, VRTX Treatment Guidelines per 7/20/2007 correspondence

Appendix A
Field Sampling Notes

Appendix B
Demonstration Project Sampling Results

Appendix C
2005 DPR Cooling Tower Active Ingredients Query Result

Appendix D
Cycles of Concentration Graphs for Demonstration Facilities

Appendix E
Cost Estimates on Potential Water and Energy Saving